

## MARAIS DES CYGNES RIVER BASIN TOTAL MAXIMUM DAILY LOAD

**Waterbody:** Cedar Creek Lake (Cedar Valley Lake)  
**Water Quality Impairment:** Eutrophication & Siltation

### 1. INTRODUCTION AND PROBLEM IDENTIFICATION

**Subbasin:** Upper Marais Des Cygnes

**Counties:** Anderson

**HUC 8:** 10290101

**HUC 10 (12):** 05 (06, 07)

**Ecoregion:** Central Irregular Plains, Osage Cuestas (40b)

**Drainage Area:** 64.8 square miles

**Conservation Pool:** Surface Area = 306 acres  
Watershed/Lake Ratio: 136:1  
Maximum Depth = 9.9 meters  
Mean Depth = 3.4 meters  
Storage Volume = 4,456 acre-feet  
Estimated Retention Time = 0.12 years  
Mean Annual Inflow = 25,266 acre-feet  
Mean Annual Discharge = 31,089 acre-feet  
Constructed: 1983

**Designated Uses:** Primary Contact Recreation Class A; Expected Aquatic Life Support; Domestic Water Supply; Food Procurement; Industrial Water Supply; Irrigation Use; Livestock Watering Use.

**303(d) Listings:** 2002, 2004, 2008, 2010 & 2012 Marais Des Cygnes River Basin Lakes

**Impaired Use:** All uses in Cedar Creek Lake are impaired to a degree by eutrophication

**Water Quality Criteria:** Nutrients - Narrative: The introduction of plant nutrients into streams, lakes, or wetlands from artificial sources shall be controlled to prevent the accelerated succession or replacement of aquatic biota or the production of undesirable quantities or kinds of aquatic life (KAR 28-16-28e(c)(2)(A)).

The introduction of plant nutrients into surface waters designated for domestic water supply use shall be controlled to prevent interference with the production of drinking water (K.A.R. 28-16-28e(c)(3)(A)).

The introduction of plant nutrients into surface waters designated for primary or secondary contact recreational use shall be controlled to prevent the development of objectionable concentrations of algae or algal by-products or nuisance growths of submersed, floating, or emergent aquatic vegetation (KAR 28-16-28e(c)(7)(A)).

Suspended Solids – Narrative: Suspended solids added to surface waters by artificial sources shall not interfere with the behavior, reproduction, physical habitat or other factors related to the survival and propagation of aquatic or semi-aquatic or terrestrial wildlife (K.A.R. 28-16-28e(c)(2)(B)).

## **2. CURRENT WATER QUALITY CONDITION AND DESIRED ENDPOINT**

**Level of Eutrophication:** Very Eutrophic, Trophic State Index = 62.0

The Trophic State Index (TSI) is derived from the chlorophyll *a* concentration. Trophic state assessments of potential algal productivity were made based on chlorophyll *a*, nutrient levels, and values of the Carlson Trophic State Index (TSI). Generally, some degree of eutrophic condition is seen with chlorophyll *a* over 12 µg/L and hypereutrophy occurs at levels over 30 µg/L. The Carlson TSI derives from the chlorophyll *a* concentrations and scales the trophic state as follows:

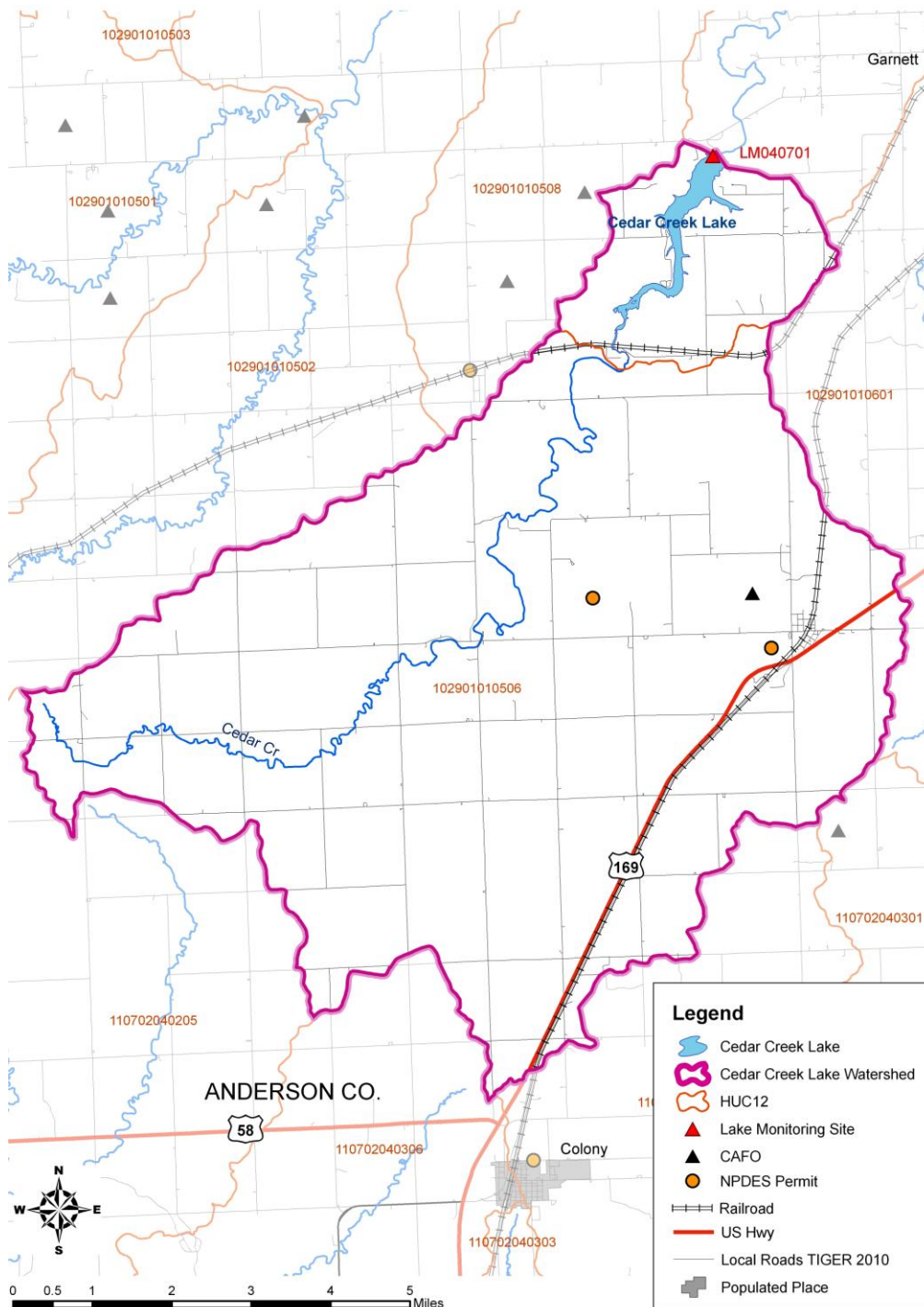
1. Oligotrophic TSI < 40
2. Mesotrophic TSI: 40 - 49.99
3. Slightly Eutrophic TSI: 50 - 54.99
4. Fully Eutrophic TSI: 55 - 59.99
5. Very Eutrophic TSI: 60 - 63.99
6. Hypereutrophic TSI: ≥ 64

**Level of Siltation Impairment:** Cedar Creek Lake has high inorganic turbidity and high levels of siltation. Sediment loads originating in the Cedar Creek headwaters are accumulating in Cedar Creek Lake, particularly in the southern end, thereby reducing the capacity of the lake. In addition, siltation is aggravated during large runoff events in the watershed.

**Lake Chemistry Monitoring Site and Period of Record Used:** KDHE Station LM040701 in Cedar Creek Lake (Figure 1). Period of Record: Six surveys conducted by KDHE in calendar years: 1993, 1998, 2002, 2006, 2009 and 2012.

**Flow Gages and Period of Record Used:** USGS Gage 06914000, Pottawatomie Creek near Garnett. Period of Record: 1/1/1990 through 9/30/2001. USGS Gage 06914100, Pottawatomie Creek near Scipio. Period of Record: 0/1/2001 through 12/31/2012.

**Figure 1.** Cedar Creek Lake Watershed.



**Hydrological Conditions:** Cedar Creek above Cedar Creek Lake is the only registered stream directly feeding Cedar Creek Lake with an estimated average flow of 31.1 cfs, according to Perry et al., 2004 (Table 1). Flow was estimated using the ratio (0.134) of the watershed size of Cedar Creek upstream from Cedar Creek Lake (44.83 mi<sup>2</sup>) to the size of the watershed at USGS Gage

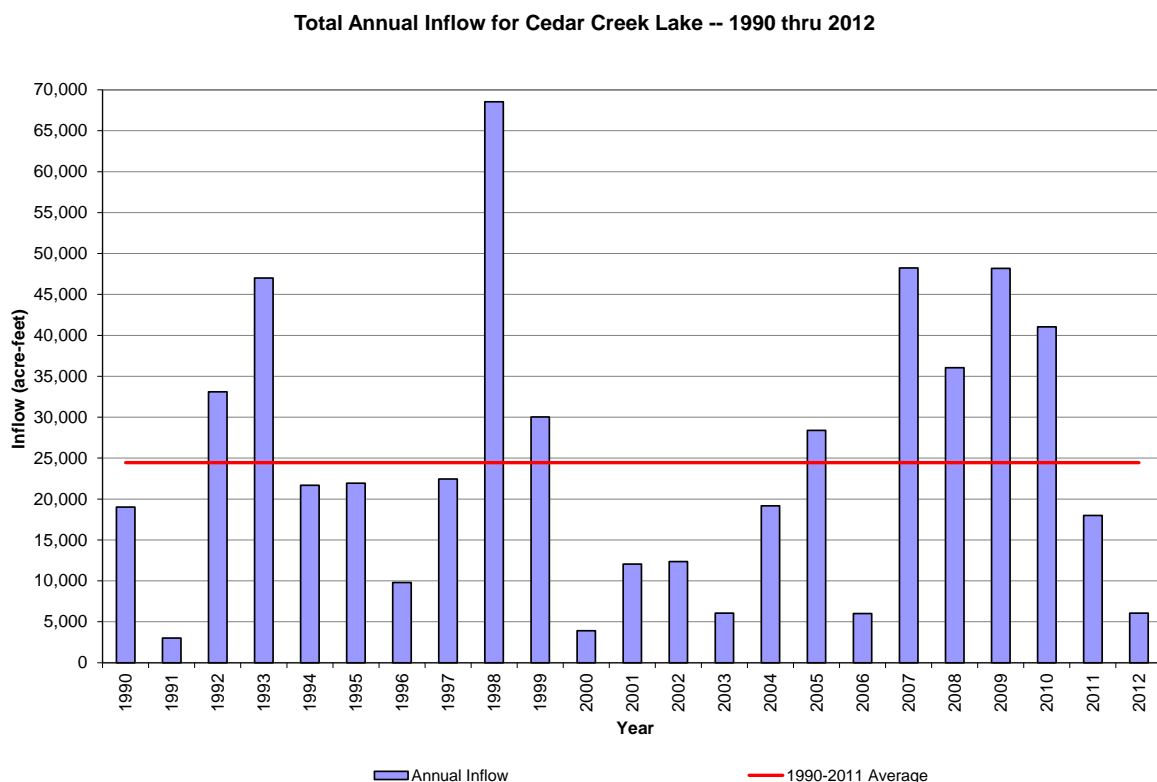
06914000 on Pottawatomie Creek near Garnett (334 mi<sup>2</sup>) for the time period of January 1, 1990 through September 30, 2001. The same technique was applied to the time period October 1, 2001 through December 31, 2012 using the ratio (0.131) of the watershed size of Cedar Creek to the size of the watershed USGS Gage 06914100 on Pottawatomie Creek near Scipio (343 mi<sup>2</sup>). Using the watershed ratio technique resulted in an estimated average inflow to Cedar Creek Lake of 33.8 cfs, or 24,438 acre-feet, for the 1990 through 2012 time period (Figure 2). According to the USGS Lake Hydro data, the mean runoff in the watershed is 9.10 inches/year; the mean precipitation in the watershed is 37.0 inches/year and the mean loss due to evaporation in the lake is 48.7 inches/year.

**Table 1.** Estimated flow duration values for Cedar Creek above Cedar Creek Lake from Perry et al., 2004 and using the watershed ratio approach. Flow values are in units of cubic-feet per second.

Stream	CUSEGA Segment	Average Flow	2-year Peak	90%	75%	50%	25%	10%
Cedar Creek (Perry)	1029010166	31.1	3,078	0.0	0.0	2.15	10.3	36.5
Cedar Creek (Watershed Ratio)	1029010166	33.8	**	0.028	0.24	2.61	13.1	55.4

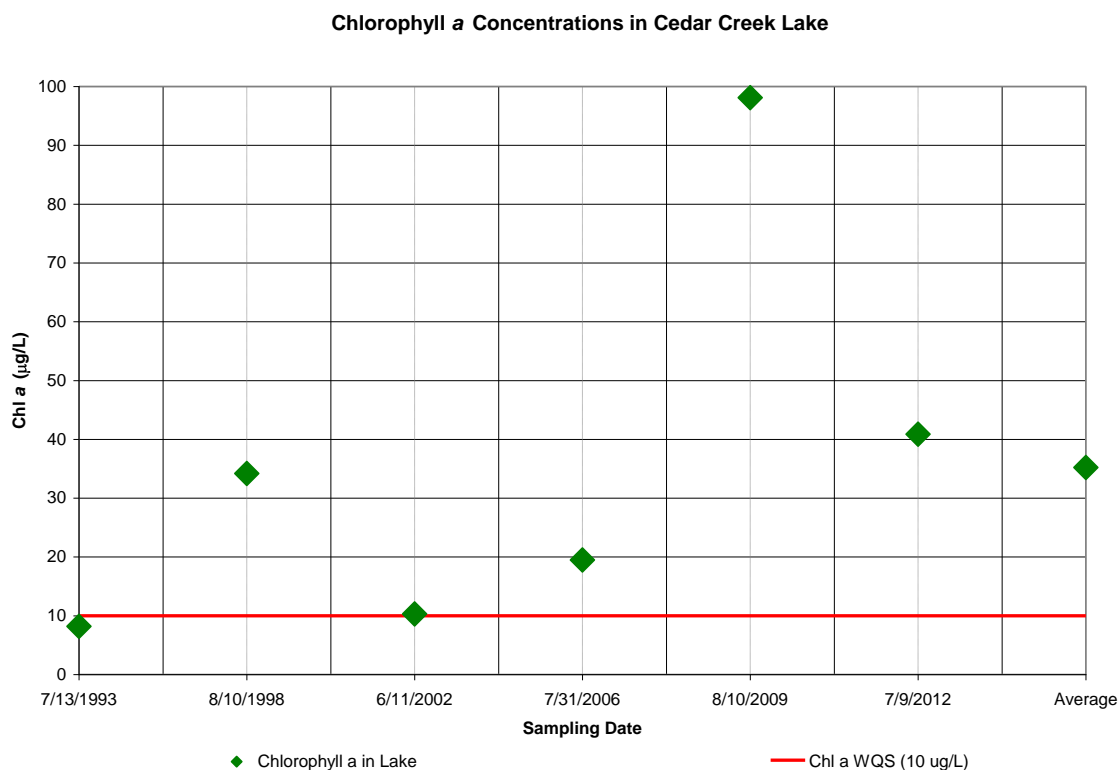
\*\*Data not available

**Figure 2.** Annual inflow to Cedar Creek Lake in acre-feet. Inflows were calculated using the watershed ratios.



**Current Conditions:** Cedar Creek Lake has chlorophyll *a* concentrations averaging 35.2 µg/L, with a corresponding Trophic State Index (TSI) value of 62.0, for the period of record. Chlorophyll *a* concentrations were measured in samples taken during the summers of 1993, 1998, 2002, 2006, 2009 and 2012 (Figure 3). Although the 2002 average of 10.3 µg/L narrowly missed meeting the 10 µg/L target, the yearly average chlorophyll *a* concentration exceeded the water quality target of 10 µg/L in all sampling years with the exception of the first recorded measurement in 1993 of 8.2 µg/L. The chlorophyll *a* concentration rose dramatically to 98.1 µg/L in 2009 and, although the concentration dropped considerably to 40.9 µg/L in 2012, the lake has been in a very eutrophic or hypereutrophic state since 2006.

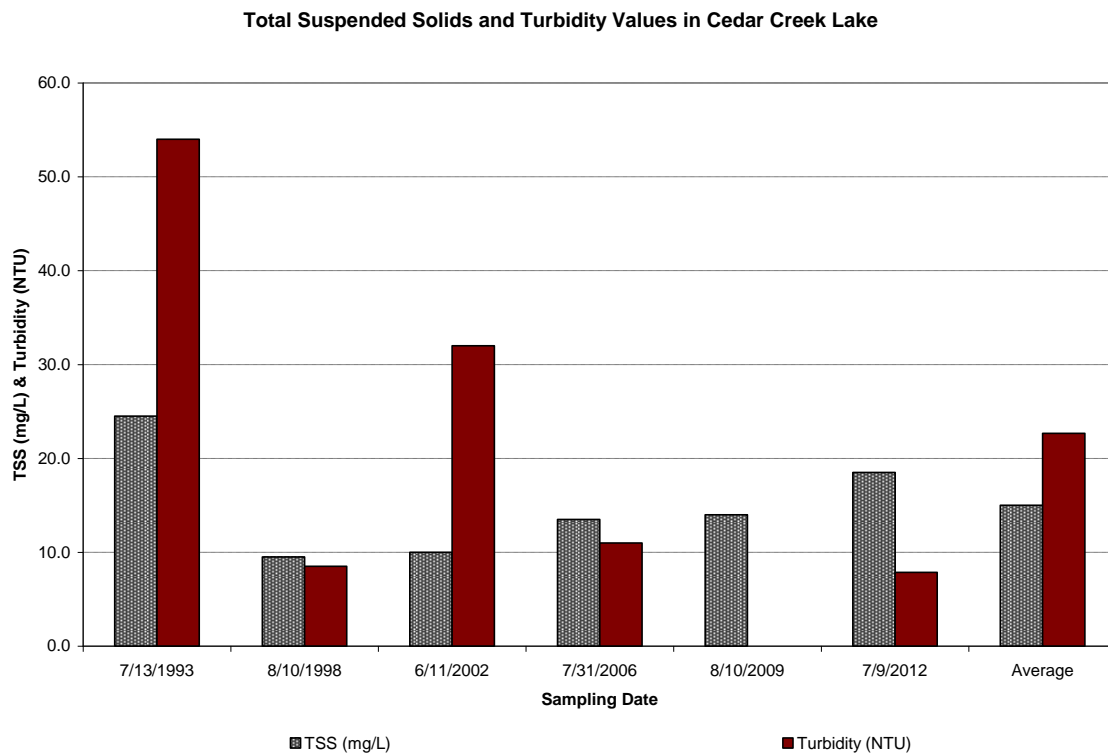
**Figure 3.** Chlorophyll *a* concentrations in Cedar Creek Lake by sampling date.



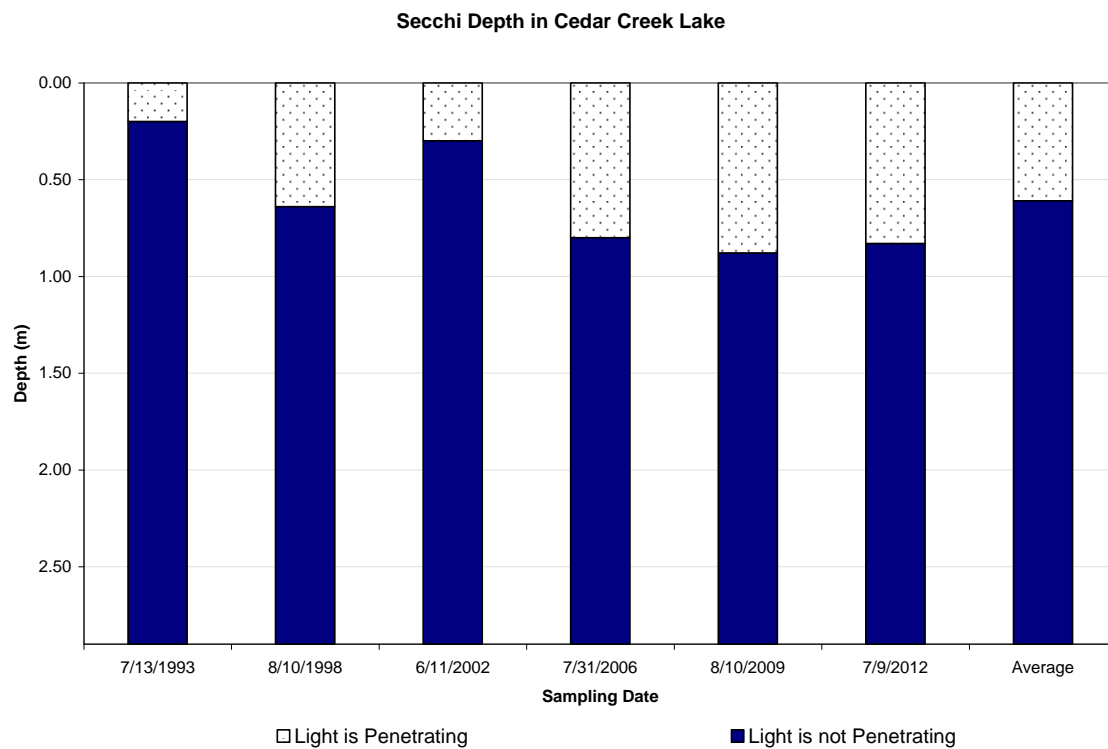
Total suspended solids (TSS) in Cedar Creek Lake ranged from 9.5 mg/L in 1998 to 24.5 mg/L in 1993 resulting in an average TSS concentration of 15.0 mg/L for the period of record (Figure 4). Average turbidity for the period of record is 22.7 NTU with values ranging from 7.86 NTU in 2012 to 54.0 NTU in 1993 (Figure 4).

Figure 5 displays the Secchi depth readings taken in Cedar Creek Lake. The shallowest reading occurred in September of 1993 at 0.20 meters while the deepest reading was taken in August 2009 at 0.88 meters. Average Secchi depth, for the period of record, is 0.61 meters.

**Figure 4.** TSS and turbidity values in Cedar Creek Lake.

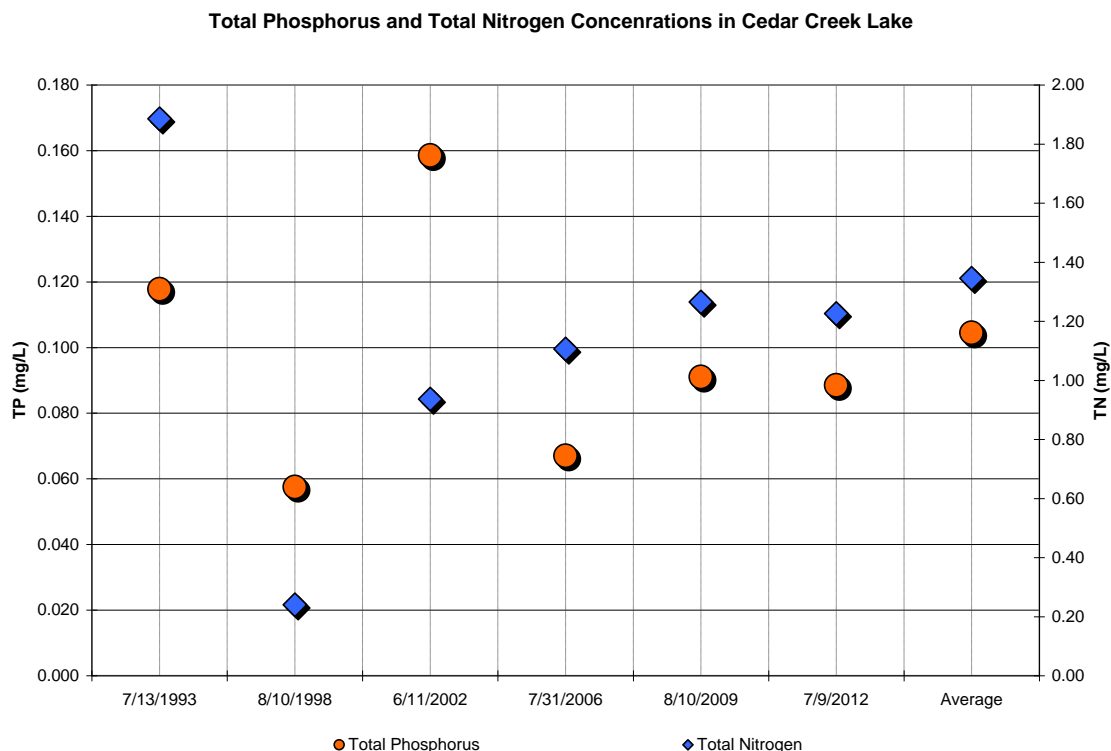


**Figure 5.** Secchi depth in Cedar Creek Lake for the period of record.



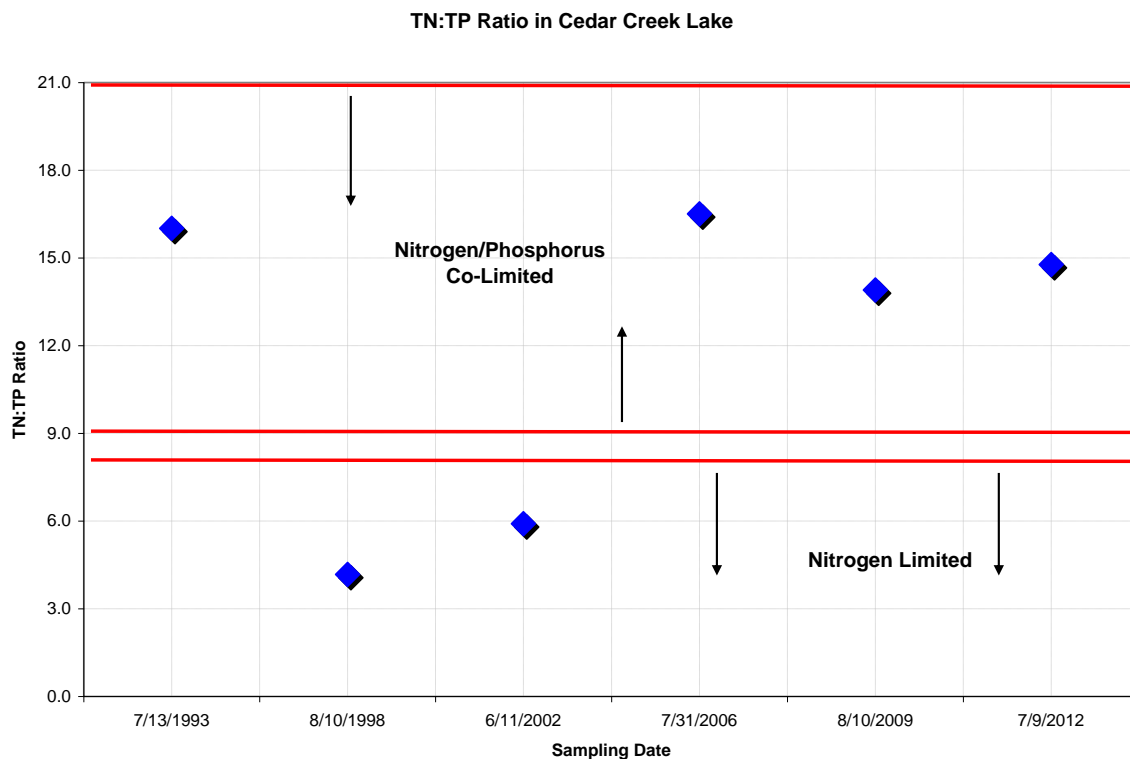
Average total phosphorus concentration in Cedar Creek Lake is 104  $\mu\text{g/L}$ , for the period of record, ranging from 58  $\mu\text{g/L}$  in 1998 to 159  $\mu\text{g/L}$  in 2002 (Figure 6). Total Nitrogen concentrations ranged from 0.240 mg/L in 1998 to 1.89 mg/L in 1993. Total nitrogen concentrations average 1.35 mg/L for the period of record (Table 2).

**Figure 6.** Average Total Phosphorus and Total Nitrogen concentration by sampling date.



The ratio of total nitrogen and total phosphorus has been used to determine which of these nutrients is most likely limiting plant growth in Kansas aquatic ecosystems. Generally, lakes that are nitrogen limited have water column TN:TP ratios < 8 (mass); lakes that are co-limited by nitrogen and phosphorus have water column TN:TP ratios between 9 and 21; and lakes that are phosphorus limited have water column TN:TP ratios > 29 (Dzialowski et al., 2005). The TN:TP ratio in Cedar Creek Lake indicates the lake was nitrogen limited in 1998 and 2002 but has been co-limited by phosphorus and nitrogen since 2006. There were no ratios above 29, hence, phosphorus alone does not appear to be limiting plant growth in Cedar Creek Lake (Figure 7).

**Figure 7.** TN:TP ratio for period of record in Cedar Creek Lake.



**Table 2.** Annual water quality averages for the years Cedar Creek Lake was sampled by KDHE. Annual precipitation totals are from NOAA station at Garnett, KS (GHCND: USC00143008). June-October 2009 precipitation is from the NOAA station at Centerville, KS (GHCND: USC00141404) as this data was not available at the Garnett station.

Year	Chl-a (µg/L)	TN (mg/L)	TP (mg/L)	TN:TP ratio	Secchi Depth (m)	Turbidity (NTU)	TSS (mg/L)	Annual Precip. (inches)
1993	8.2	1.89	0.118	16.0	0.20	54.0	24.5	50.0
1998	34.2	0.240	0.058	4.17	0.64	8.50	9.50	59.8
2002	10.3	0.937	0.159	5.91	0.30	32.0	7.50	33.7
2006	19.5	1.11	0.067	16.5	0.80	11.0	13.5	27.0
2009	98.1	1.27	0.091	13.9	0.88	*	14.0	46.0
2012	40.9	1.23	0.089	14.8	0.83	7.86	18.5	27.5
<b>Average</b>	<b>35.2</b>	<b>1.35</b>	<b>0.104</b>	<b>13.0</b>	<b>0.61</b>	<b>22.7</b>	<b>15.0</b>	<b>40.7</b>

\*Data not available

Table 3 lists the six metrics measuring the roles of light and nutrients in Cedar Creek Lake. Non-algal turbidity (NAT) values  $<0.4\text{m}^{-1}$  indicates there are very low levels of suspended silt and/or clay. The values between  $0.4$  and  $1.0\text{m}^{-1}$  indicate inorganic turbidity assumes greater influence on water clarity but would not assume a significant limiting role until values exceed  $1.0\text{m}^{-1}$ .

**Table 3.** Cedar Creek Lake limiting factor metrics.

Sampling Year	Non-algal Turbidity	Light Availability in the Mixed Layer	Partitioning of Light Extinction between Algae & Non-algal Turbidity	Algal use of Phosphorus Supply	Light Availability in the Mixed Layer for a Given Surface Light	Shading in Water Column due to Algae and Inorganic Turbidity	Chl- <i>a</i> (µg/L)
	<b>NAT</b>	<b>Zmix*NAT</b>	<b>Chl-a*SD</b>	<b>Chl-a/TP</b>	<b>Zmix/SD</b>	<b>Shading</b>	
1993	4.70	16.1	1.64	0.0550	17.2	11.7	8.20
1998	0.822	2.82	21.9	0.595	5.36	7.57	34.2
2002	2.99	10.3	3.09	0.0650	11.4	9.03	10.3
2006	0.744	2.55	15.6	0.291	4.29	6.13	19.5
2009	0	0	86.3	1.08	3.90	10.5	98.1
2012	0.362	1.24	33.9	0.646	4.13	7.27	40.9

The depth of the mixed layer in meters (Z) multiplied by the NAT value assesses light availability in the mixed layer. There is abundant light within the mixed layer of the lake and potentially a high response by algae to nutrient inputs when this value is less than 3. Values greater than 6 would indicate the opposite.

The partitioning of light extinction between algae and non-algal turbidity is expressed as Chl-*a*\*SD (Chlorophyll *a* \* Secchi Depth). Inorganic turbidity is not responsible for light extinction in the water column and there is a strong algal response to changes in nutrient levels when this value is greater than 16. Values less than 6 indicate that inorganic turbidity is primarily responsible for light extinction in the water column and there is a weak algal response to changes in nutrient levels.

Values of algal use of phosphorus supply (Chl-*a*/TP) that are greater than 0.4 indicate a strong algal response to changes in phosphorus levels, where values less than 0.13 indicate a limited response by algae to phosphorus.

The light availability in the mixed layer for a given surface light is represented as Zmix/SD. Values less than 3 indicate that light availability is high in the mixed zone and there is a high probability of strong algal responses to changes in nutrient levels.

Shading values less than 16 indicate that self-shading of algae does not significantly impede productivity. This metric is most applicable to lakes with maximum depths of less than 5 meters (Carney, 2004).

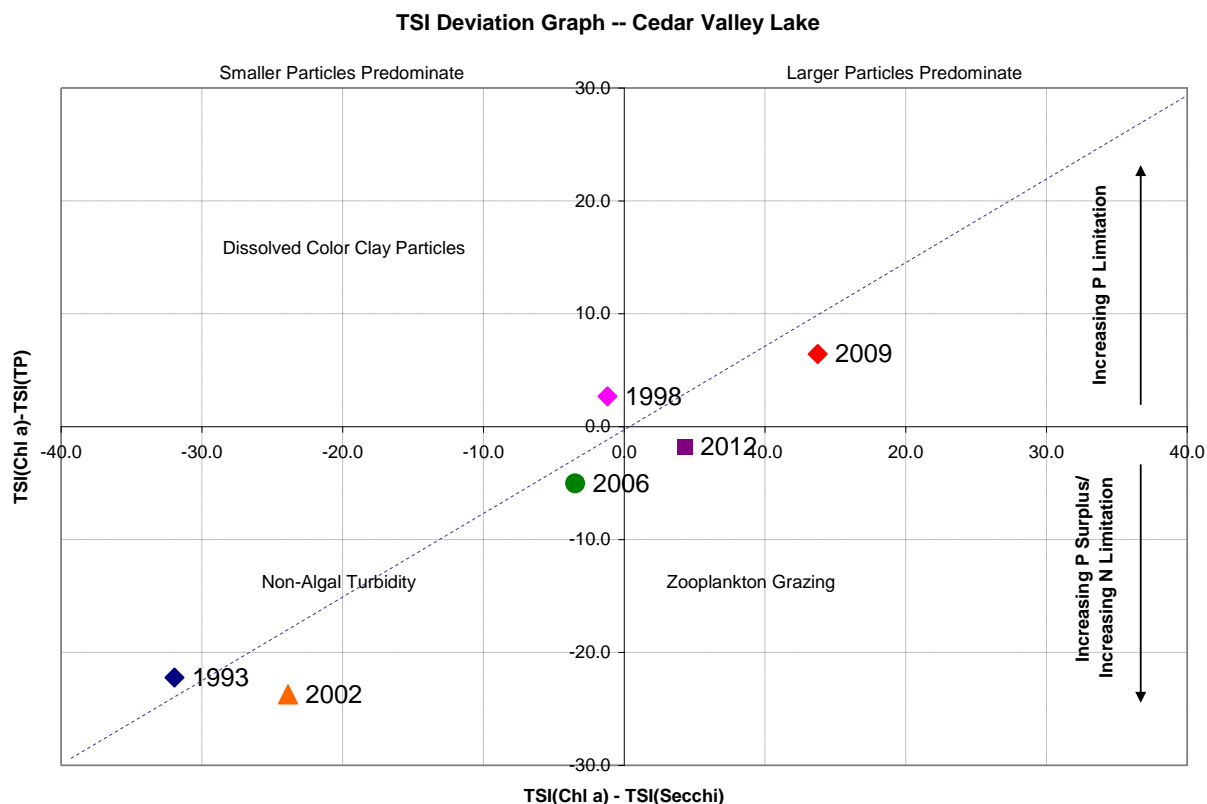
The above metrics indicate that inorganic turbidity in Cedar Creek Lake was responsible for diminished light availability in the mixed layer in 1993 and 2002 causing algae to be slow to respond to phosphorus inputs and leading to the low chlorophyll *a* concentrations of 8.20 µg/L in 1993 and 10.3 µg/L in 2002. In 1998, 2009, and 2012 there were moderately low levels of inorganic turbidity in Cedar Creek Lake allowing for abundant light in the mixed layer and a strong response to phosphorus inputs by algae in the lake as indicated by chlorophyll *a* concentrations greater than 30 µg/L for all three years. In 2006, inorganic turbidity was low enough to allow abundant light into the mixed layer; however, the phosphorus supply was not utilized by the algae in the lake to the same degree as it was in 1998, 2009 and 2012 resulting in

a lower chlorophyll *a* concentration of 19.5 µg/L. For the period of record, self shading of algae does not appear to be impeding productivity in the lake.

Another method for evaluating limiting factors is the TSI deviation metrics. Figure 7 (Multivariate Deviation Graph) summarizes the current trophic conditions at Cedar Creek Lake using a multivariate TSI comparison chart for the period of record. Where TSI(Chl-*a*) is greater than TSI(TP), the situation indicates phosphorus is limiting chlorophyll *a*, whereas negative values indicate turbidity limits chlorophyll *a*. Where TSI(Chl-*a*)-TSI(SD) is plotted on the horizontal axis, if the Secchi depth (SD) trophic index is less than the chlorophyll *a* trophic index, then there is dominant zooplankton grazing. Transparency would be dominated by non-algal factors such as color or turbidity if the Secchi depth index were more than the chlorophyll *a* index. Points near the diagonal line occur in turbid situations where phosphorus is bound to clay particles and therefore turbidity values are closely associated with phosphorus concentrations.

The multivariate TSI comparison chart in Figure 8 displays that there were high levels of non-algal turbidity in Cedar Creek Lake in 1993 and 2002 while the proximity of the 1998, 2006, 2009 and 2012 points to the diagonal line is indicative of phosphorus bound to the clay particles in the water column. The lake was moderately turbid in 2006 with some zooplankton grazing occurring in 2012

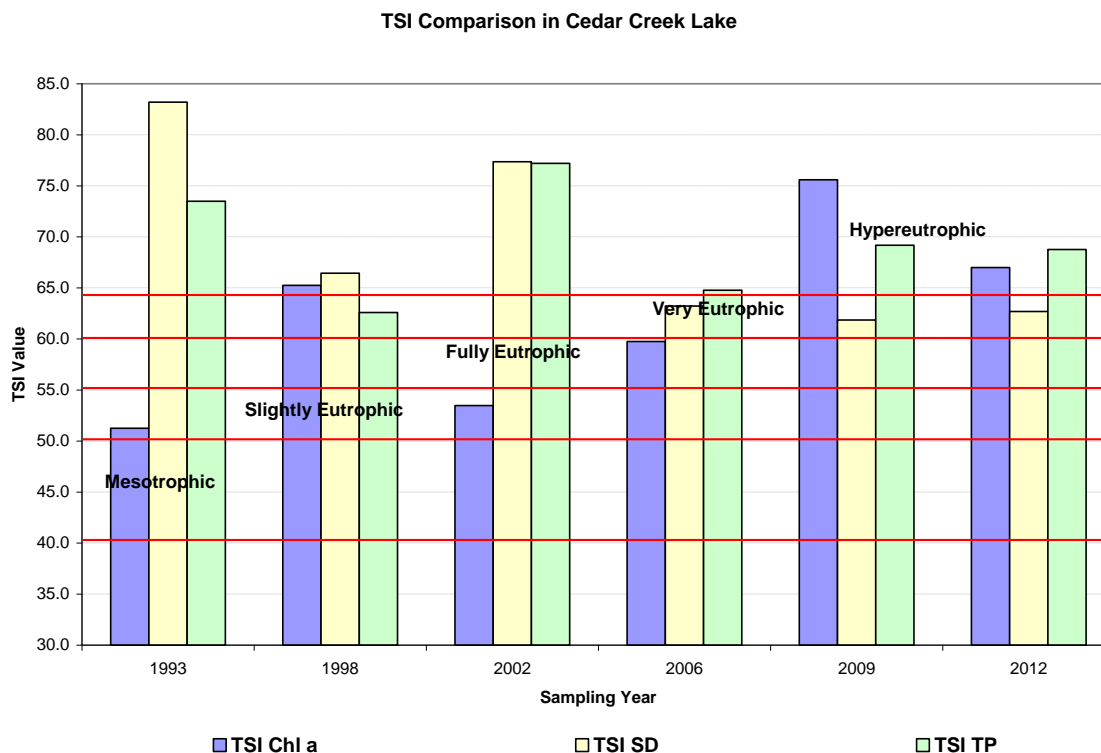
**Figure 8.** Multivariate TSI comparison chart for Cedar Creek Lake.



The Carlson Trophic State Index for chlorophyll *a* in Cedar Creek Lake shown in Figure 9 reveals the lake has moved from a slightly eutrophic state in 2002 to a hypereutrophic state in

2009. The Secchi depth index, however, has improved to a very eutrophic state over the period of record while the total phosphorus index reflects a hypereutrophic state in all years except 1998.

**Figure 9.** Cedar Creek Lake Trophic State Indices.



A comparison of the median trophic conditions in Cedar Creek Lake to the benchmarks established for lakes in Kansas reveals they do not meet any of the benchmarks (Table 4). The statewide benchmarks and benchmarks for Kansas lakes in the central irregular plains region were derived from analysis of trophic conditions in the lakes and reservoirs in Kansas (Dodds et al., 2006). RTAG benchmarks were established by the USEPA Region 7 Regional Technical Assistance Group (RTAG) and are for lakes and reservoirs in Kansas, Iowa, Missouri and Nebraska excluding the Sand Hills ecoregion (USEPA, 2011).

**Table 4.** Median trophic indicator values for Cedar Creek Lake in comparison with federal lakes in Kansas, lakes located in the central irregular plains ecoregion, draft nutrient benchmarks in Kansas and nutrient reference conditions for lakes in USEPA Region 7.

Trophic Indicator	Cedar Creek Lake	Federal Lakes	Central Irregular Plains Lakes	Statewide Benchmark	RTAG
Secchi Depth (cm)	61	95	130	129	N/A
TN ( $\mu\text{g/l}$ )	1,345	903	362	625	700
TP ( $\mu\text{g/l}$ )	104	76	20	23	35
Chlorophyll <i>a</i> ( $\mu\text{g/l}$ )	35	12	8	8	8

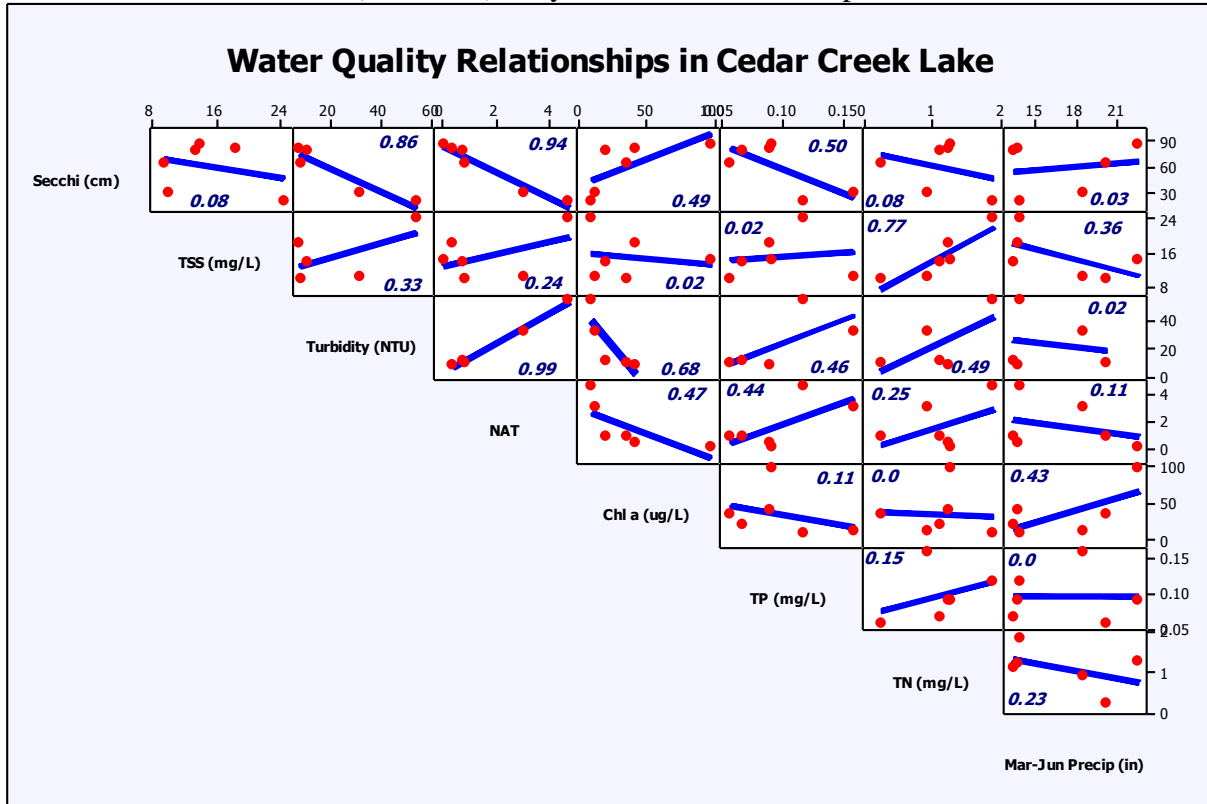
**Algal Communities:** As seen in Table 5, algal communities in Cedar Creek Lake have been dominated by blue-green algae, or cyanobacteria, since 2006. An increasing supply of nutrients, especially phosphorus and possibly nitrogen, will often result in higher growth of blue-green algae because they possess certain adaptations that enable them to out compete true algae (Soil and Water Conservation Society of Metro Halifax, 2007). Several of the cyanobacteria species possess gas vacuoles that allow them to move within the water column vertically. This selective advantage allows for some species to move within the water column to avoid predation and reach optimal primary productivity. Their movement within the water column may influence chlorophyll *a* levels within the lake at various depths during the diel cycle.

**Table 5.** Algal communities observed in Cedar Creek Lake in 1993, 1998, 2002, 2006, 2009 and 2012.

Sampling Date	Total Cell Count cells/mL	Percent Composition				Chl- <i>a</i> µg/L
		Green	Blue Green	Diatom	Other	
1993	3,150	24	0	0	76	8.2
1998	37,832	17	25	54	4	34.2
2002	1,292	41	0	8	51	10.3
2006	28,098	14	78	6	<2	19.5
2009	167,426	4	89	5	2	98.1
2012	100,737	7	88	3	<2	40.9

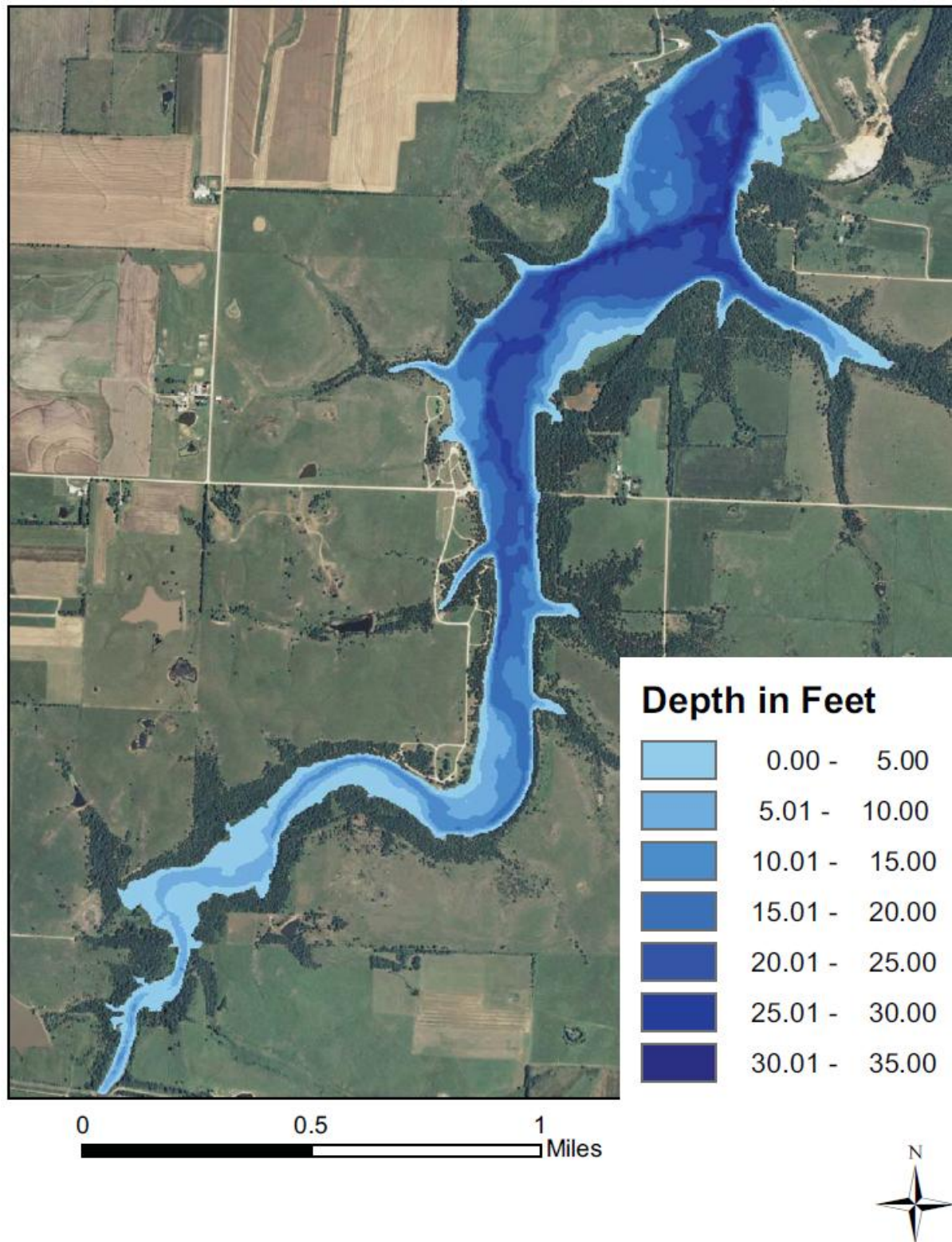
**Relationships:** Within Cedar Creek Lake there are strong relationships between: turbidity and non-algal turbidity (NAT); turbidity and Secchi depth; turbidity and chlorophyll *a*; and total suspended solids (TSS) and total nitrogen (TN) (Figure 10). There are moderate relationships between: turbidity and total phosphorus (TP); turbidity and TN; TN and spring precipitation; turbidity and spring precipitation; chlorophyll *a* and spring precipitation and Secchi depth and TP. Two of the relationships: Secchi depth and NAT and chlorophyll *a* and NAT are related to one another while the moderately strong relationships of Secchi depth and chlorophyll *a* and TSS and spring precipitation are the inverse of what one would expect to see. The remaining relationships are weak or non-existent in Cedar Creek Lake.

**Figure 10.** Relationships of water quality parameters in Cedar Creek Lake with associated coefficient of determination ( $R^2$  values) for years the lake was sampled.



**Bathymetric Survey:** A bathymetric and sediment survey performed by Kansas Biological Survey in 2009 revealed high percentages of silt and clay in the sediment of Cedar Creek Lake. Silt and clay make up 60% and 40% of the sediment, respectively, in the southern portion of the lake. Near the center of the lake the sediment is 32% silt and 68% clay while nearer the dam the sediment is made up of 46% silt and 54% clay. Sediment and nutrient loads appear to derive from Cedar Creek and from the drainage channels on the east side of the lake as the lake is shallower here than along the west edge of the lake (Figure 11).

**Figure 11.** Water depth in Cedar Creek Lake based on November 6, 2009 bathymetric survey. Depths are based on a pool elevation of 969.26 feet (KBS, 2010).



**Stream Data:** No water quality data was available for Cedar Creek (CUSEGA 1029010166).

### **Desired Endpoints of Water Quality (Implied Load Capacity) in Cedar Creek Lake:**

The ultimate endpoint for this TMDL will be to achieve the Kansas Water Quality Standards fully supporting the designated uses in Cedar Creek Lake by eliminating impacts associated with excessive siltation and excessive eutrophication. In order to improve the trophic condition of Cedar Creek Lake from its current Very Eutrophic status, the desired endpoint will be to maintain summer chlorophyll *a* average concentrations below 10 µg/L, corresponding to a Carlson Trophic State Index of 53.2, with the reductions focused on nutrients (TN and TP) entering the lake. Reduction in nutrient loading will address the accelerated succession of aquatic biota and the development of objectionable concentrations of algae and algae by-products as determined by the chlorophyll *a* concentration in the lake. A chlorophyll *a* endpoint of 10 µg/L will also ensure long-term protection to fully support Primary Contact Recreation within the lake.

In order to improve the quality of the water column and the siltation impairment, an 18% reduction of the in-lake total suspended solids concentration from 15.0 mg/L to 12.3 mg/L has been established (Appendix C). Reductions in sediment loading from the watershed will achieve the 12.3 mg/L TSS target thereby improving the average transparency of the lake to the endpoint of 0.9 meters, as measured by the Secchi disk depth within the main basin of the lake.

Based on the BATHTUB reservoir eutrophication model (Appendix A), the total phosphorus entering the lake must be reduced by 80% and the total nitrogen entering the lake must be reduced by 69%. These reductions at the inflow to Cedar Creek Lake will result in a 71% reduction of total phosphorus, a 65% reduction of total nitrogen, and a 72% reduction of Chlorophyll *a* within the lake (Table 6).

Achievement of the endpoints indicates loads are within the loading capacity of the lake, the water quality standards are attained, and full support of the designated uses of the lake has been achieved. Seasonal variation has been incorporated in this TMDL since the peaks of algal growth occur in the summer months. The current average condition for Cedar Creek Lake utilized in the model input was based on KDHE data at LM040701, for the period of record. Water quality data for the Cedar Creek tributary was estimated by adjusting tributary nutrient inputs in the BATHTUB model until the current condition in the lake was generated upon running the model.

**Table 6.** Cedar Creek Lake Current average condition and TMDL.

	<b>Current Avg. Condition</b>	<b>TMDL</b>	<b>Percent Reduction</b>
Total Phosphorus – Annual Load (lbs/year)	20,673	4,161	80%
Total Phosphorus – Daily Load* (lbs/day)	112	22.4	80%
Total Phosphorus – Lake Concentration (µg/L)	104	30.2	71%
Total Nitrogen – Annual Load (lbs/year)	121,256	38,031	69%
Total Nitrogen – Daily Load* (lbs/day)	836	262	69%
Total Nitrogen – Lake Concentration (mg/L)	1.345	0.477	65%
Chlorophyll <i>a</i> Concentration (µg/L)	35.2	10	72%
Total Suspended Solids – Annual Load (tons/year)	7,571.3	6,208.5	18%
Total Suspended Solids – Daily Load* (tons/day)	46.01	37.73	18%
Total Suspended Solids Concentration (mg/L)	15.0	12.3	18%
Secchi Depth (m)	0.6	0.9	50% Increase

\*See Appendix B for Daily Load Calculations

### 3. SOURCE INVENTORY AND ASSESSMENT

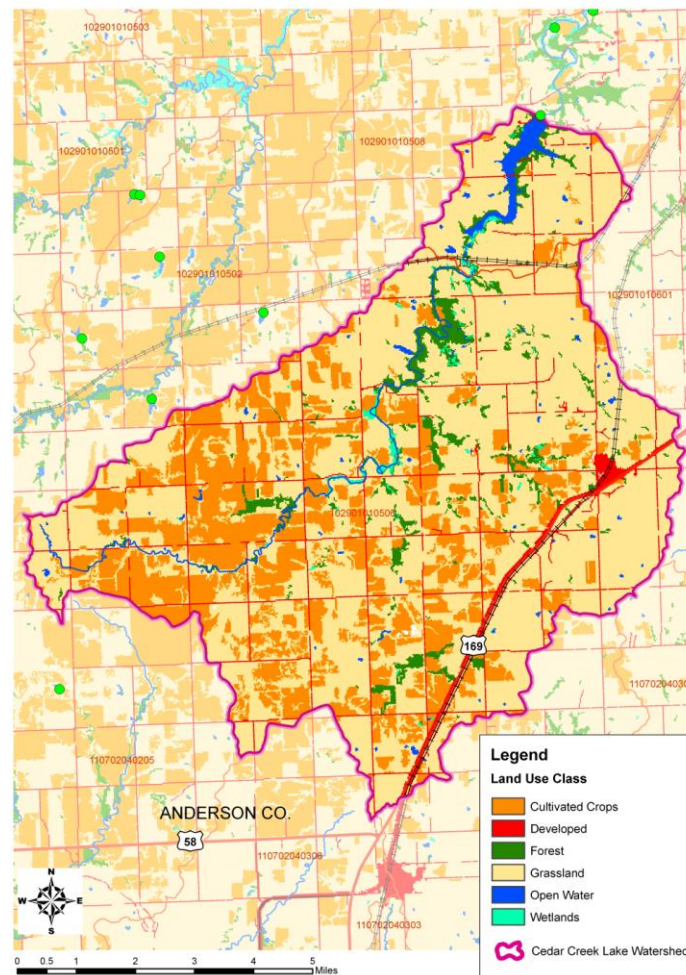
**Point Sources:** There are two NPDES permitted facilities in the Cedar Creek Lake watershed. One is a discharging lagoon system operated by the Welda Sewer District while the second is a de-watering/stormwater pit operated by a limestone quarrying and crushing operation that would only contribute a waste load under extreme precipitation or flooding events (Table 7).

**Table 7.** Discharge permits in the Cedar Creek Lake watershed.

<b>Permittee</b>	<b>NPDES Permit #</b>	<b>State Permit #</b>	<b>Type</b>	<b>Expiration Date</b>
Welda Sewer District No. 1	KS0096946	M-MC53-OO01	3 Cell Lagoon	12/31/2014
Whitaker Companies	KS0116025	I-MC53-PO01	De-watering/ Stormwater	4/30/2014

**Land Use:** The predominant land uses in the Cedar Creek Lake watershed are grassland (63.1%) and cultivated crops (26.0%), according to the 2001 National Land Cover Data. Together they account for 89.1% of the total land area in the watershed with the remaining land area composed of developed land (4.5%), forest (4.3%), open water (1.3%) and wetlands (0.68%) (Figure 12).

**Figure 12.** Land use in the Cedar Creek Lake watershed.



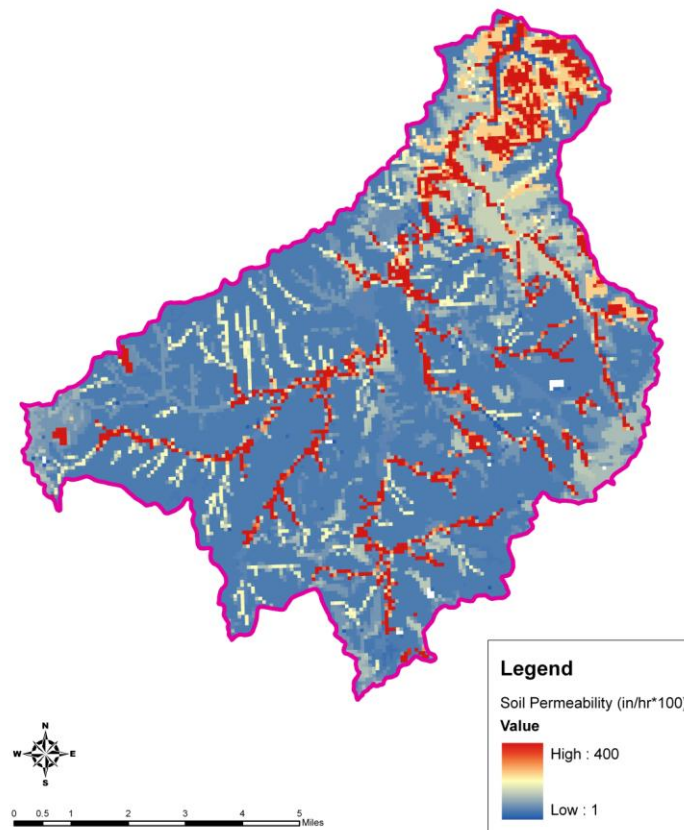
**Livestock Waste Management Systems:** There is one active, certified confined animal feeding operation (CAFO) in the Cedar Creek Lake watershed with an inventory of 500 head of cattle (Permit: A-MCAN-BA04). It is likely, however, that there are other unregistered livestock feeding operations in the watershed. The 2007 Census of Agriculture reported a cattle inventory of 34,900 head in Anderson County with no other animal totals reported.

**On-Site Waste Systems:** The Cedar Creek Lake watershed is a rural agricultural area that lies in Anderson County. It can be assumed that all of the rural residences in the watershed are not connected to public sewer systems and, according to Spreadsheet Tool for Estimating Pollutant Load (STEPL), there are a total of 203 septic systems in the watershed with a 0.93% failure rate. Failing on-site septic systems have the potential to contribute to nutrient loading in the watershed.

**Population:** According to the 2010 U.S. Census, the population of the Cedar Creek Lake watershed was 332 people giving a population density of about 5 people per square mile. In Anderson County, the 2010 U.S. Census reported a population of 8,102 people, a -0.1% decrease from the 2000 U.S. Census.

**Contributing Runoff:** The watershed of Cedar Creek Lake has a low mean soil permeability value of 0.30 inches/hour. Permeability ranges from 0.01 inches/hour to 1.29 inches/hour according to NRCS STATSGO database with over 50% of the watershed having a permeability value less than 0.57 inches/hour, which contributes to runoff during extremely low rainfall intensity events. 26% of the Cedar Creek Lake watershed has a permeability value of 1.29 inches/hour, generating runoff during very low to low rainfall intensities (Figure 13). According to a USGS open-file report (Juracek, 2000), the threshold soil-permeability values are set at 3.43 inches/hour for very high, 2.86 inches/hour for high, 2.29 inches/hour for moderate, 1.71 inches/hour for low, 1.14 inches/hour for very low, and 0.57 inches/hour for extremely low soil-permeability. Runoff is primarily generated as infiltration excess with rainfall intensities greater than soil permeability. As the watershed's soil profiles become saturated, excess overland flow is produced.

**Figure 13.** Soil permeability in the Cedar Creek Lake watershed.



**Background and Natural Sources:** Undissolved nutrients bound to suspended solids in the inflow to Cedar Creek Lake are potentially significant sources of nutrients that may endure in the sediment layer until they are removed by dredging. These internal nutrient loads can undergo remineralization and resuspension and may be a continuing source of nutrients in Cedar Creek Lake. In addition, geological formations (i.e. soil and bedrock) may also contribute to nutrient loads and, with deciduous forest making up about 5% of the land cover in the watershed, leaf litter and wastes derived from natural wildlife in the area are also likely to add to the nutrient and suspended solids load in Cedar Creek Lake. Further nutrient loading is also occurring through

the atmospheric deposition of nitrogen and phosphorus compounds to Cedar Creek Lake and its watershed.

#### 4. ALLOCATION OF POLLUTANT REDUCTION RESPONSIBILITY

Phosphorus and nitrogen are co-limiting nutrients in Cedar Creek Lake and, as such, both phosphorus and nitrogen will both be allocated under this TMDL. To address the siltation impairment, a Secchi depth target of 0.9 m will be met by allocating sediment loads under this TMDL.

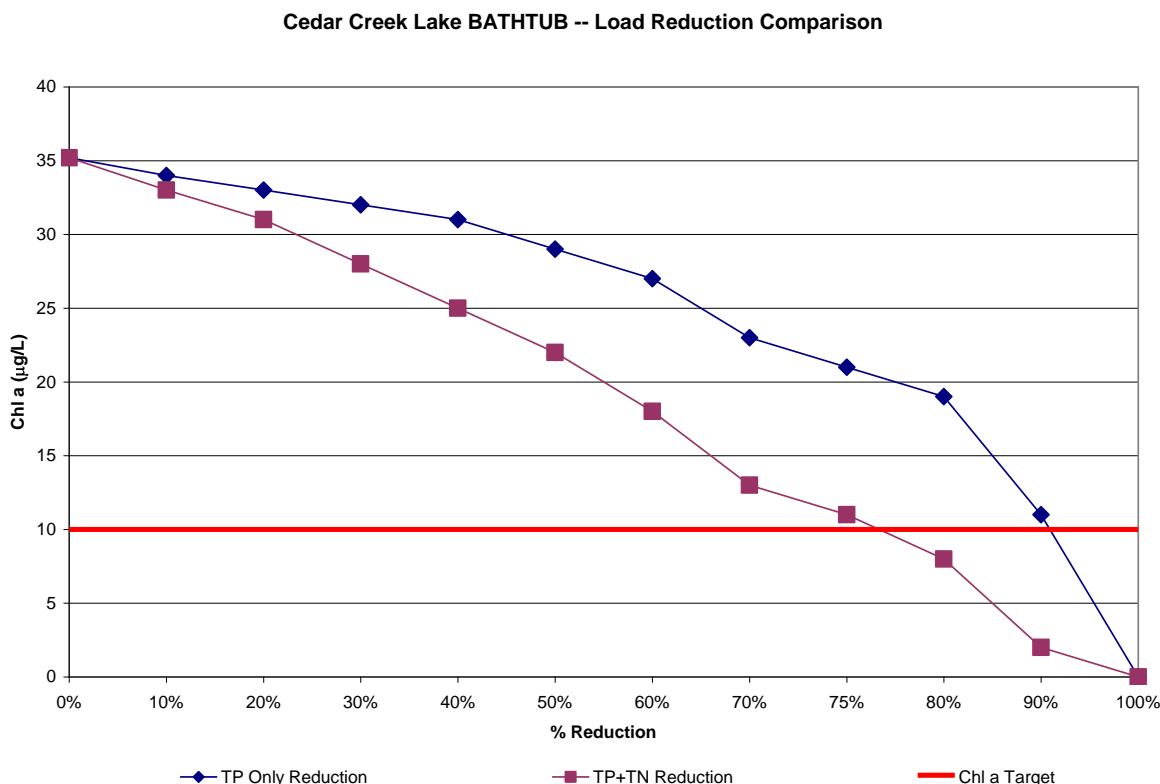
**Nutrients:** The lake model utilized for the development of the nutrient TMDL was BATHTUB. BATHTUB is an empirical receiving water quality model, that was developed by the U.S. Army Corps of Engineers (Walker, 1996), and has been commonly applied in the nation to address many TMDLs relating to issues associated with morphometrically complex lakes and reservoirs (Mankin et al., 2003; Wang et al., 2005). Cedar Creek Lake was considered one segment for the BATHTUB model. Atmospheric total nitrogen was obtained from the Clean Air Status and Trends Network (CASTNET), which is available at <http://www.epa.gov/castnet>. The CASTNET station from the Konza Prairie (KS) was used to estimate the atmospheric TN concentration for the model. Total phosphorus atmospheric loading was estimated using the 1983 study of Rast and Lee. Water quality data for the main basin segment was averaged using the 1993, 1998, 2002, 2006, 2009 and 2012 data from KDHE (LM040701). Model input data for the tributary Cedar Creek was estimated by adjusting tributary nutrient inputs in the BATHTUB model until the current condition in the lake was generated upon running the model. This resulted in tributary inputs for Cedar Creek of 310 µg/L of total phosphorus and 1,786 µg/L of total nitrogen. Annual flow for Cedar Creek was estimated at 30.2 hm<sup>3</sup>/year based on the 1990-2012 calculated average flow of 33.8 cfs (Table 8). The BATHTUB model was calibrated for Cedar Creek Lake and results (Appendix A) estimate that the lake retains 52% of the TP and 18% of the TN load annually. Based on modeling results, the combined reduction of TP and TN results in reaching the chlorophyll *a* endpoint more readily than reducing TP alone (Figure 14). Hence, an 80% reduction of TP and a 69% reduction of TN within the inflow to Cedar Creek Lake are necessary to achieve the TMDL endpoint of 10 µg/L of Chlorophyll *a* within Cedar Creek Lake.

**Table 8.** Current condition nutrients in Cedar Creek and Cedar Creek Lake.

<b>Parameter</b>	<b>Concentration or Load</b>
Cedar Creek Total Phosphorus (µg/L)	310
Cedar Creek Total Nitrogen (µg/L)	1,786
Average Flow in Cedar Creek (hm <sup>3</sup> /year)	30.2
Current Total Phosphorus Load (lbs/year)	20,673
Current Total Nitrogen Load (lbs/year)	121,256
<b><i>Current Daily Total Phosphorus Load (lbs/day)*</i></b>	<b><i>112</i></b>
<b><i>Current Daily Total Nitrogen Load (lbs/day)*</i></b>	<b><i>836</i></b>

\*See Appendix B for Daily Load Calculations

**Figure 14.** Changes in chlorophyll *a* levels in relation to watershed nutrient reduction.



**Siltation:** Siltation loading comes predominantly from nonpoint source pollution. Based on the soil characteristics of the watershed, overland runoff can easily carry sediment to the stream segments and eventually to the lake. Though Kansas does not have numeric water quality criteria from inorganic turbidity associated with soil/sediment particles (often referred to as non-algal turbidity), “Brown” scores, derived from 1998-2002 statewide lake monitoring (Carney, 2003), were utilized as a guideline to the appearance of low water clarity as a result of non-algal turbidity. To achieve full support status, a Secchi depth of 0.9 m is the target for addressing the siltation portion of this TMDL with reductions focused on the total suspended solids entering the lake. An estimate of the sediment being deposited in the lake was calculated by first calculating the amount of sediment exiting the lake using the lake capacity provided by the 2009 KBS Bathymetric survey, lake retention time, and recent TSS average concentration. The sediment exiting the lake is calculated to be:

$$\text{Tons of Sediment/Year Exiting Cedar Creek Lake} = [\text{Lake Volume (4,456 ac-ft)}] * [\text{TSS (15.0 mg/L)}] * [\text{Lake Retention Time (365 days/retention time (43.8 days))}] * [\text{Unit Conversion Factors (1,233,482 L/ac-ft)}] * (2.204 \text{ lbs/1,000,000 mg}) * (1 \text{ ton/2000 lbs})]$$

$$= 757 \text{ tons of sediment exiting Cedar Creek Lake annually}$$

Assuming a 90% trapping efficiency of the lake, the annual amount of sediment exported from the watershed to the lake, annually, is calculated to be:

$$757 \text{ tons/year exiting} / 0.1 \text{ (assumes a 90\% trapping efficiency)}$$

$$= 7,571 \text{ tons of sediment exported from the watershed annually}$$

Subtracting the sediment exiting the lake from the total tons of sediment exported from the watershed results in tons of sediment deposited in the lake annually:

$$7,571 \text{ tons (exported annually from watershed)} -$$

$$757 \text{ tons (exiting the lake annually)}$$

$$= 6,814 \text{ tons of sediment deposited annually in Cedar Creek Lake}$$

**Table 9.** Current condition sediment retention in Cedar Creek Lake.

<b>Parameter</b>	<b>Cedar Creek Lake LM040701</b>
Volume (acre-feet)	4,456
Retention Time (days)	43.8
Average TSS Concentration (mg/L)	15.0
Trapping Efficiency	90%
<b><i>Total Sediment Exported from Watershed (tons/year)</i></b>	<b><i>7,571</i></b>
<b><i>Current Sediment Exiting Lake (tons/year)</i></b>	<b><i>757</i></b>
<b><i>Current Annual Sediment Retention (tons/year)</i></b>	<b><i>6,814</i></b>
<b><i>Current Daily Sediment Load (tons/day)*</i></b>	<b><i>46.01</i></b>

\*See Appendix B for Daily Load Calculations

The sediment TMDL was calculated in the same manner as the current condition using a target TSS concentration of 12.3 mg/L in Cedar Creek Lake. The TSS target of 12.3 mg/L was developed using the in lake relationship between Secchi depth and turbidity and turbidity and TSS concentration as displayed in Appendix C. This reduction in TSS concentration in the lake results in an 18% reduction in sediment load for a TMDL of 37.73 tons/day (Table 11).

**Point Sources:** A wasteload allocation is established for the discharging wastewater treatment facility permitted within the watershed. This allocation applies to the Welda Sewer District No.1. and is set at 116 lbs of total phosphorus and 464 pounds of total nitrogen per year (Table 10). The wasteload allocation is based on discharging at the design flow of 19,000 gpd with a concentration of 2 mg/L total phosphorus and 8 mg/L total nitrogen, which are typical concentrations associated with lagoon systems. This wastewater treatment plant will comply with any future permit limits for nitrogen and phosphorus. The wasteload allocation for total suspended solids (TSS) is 4,636 pounds per year, based on the current monthly average TSS limit of 80 mg/L, which is in place for this facility (Table 11). The established wasteload allocation is conservative as actual flow originating from this facility is not reported and the current wasteload is likely less. A wasteload allocation of zero is applied to the non-discharging quarry in the watershed.

**Nonpoint Sources:** Nonpoint sources are the primary contributors for the nutrient and sediment input and impairment in Cedar Creek Lake. Background levels may be attributed to nutrient recycling and leaf litter. The assessment suggests that runoff transporting nutrient and suspended

sediment loads associated with animal wastes and fertilized cultivated cropland and pastureland is contributing to siltation and eutrophication in the lake. Nutrient load allocations were calculated using the BATHTUB model (Appendix A). Sediment loads were calculated using the average in-lake TSS concentration and lake trapping efficiency while the needed TSS load reduction was based on the relationships between TSS and Secchi depth (Appendix C).

**Table 10.** Cedar Creek Total Phosphorus and Total Nitrogen TMDL

Description	Allocations (lbs/year)	Allocations (lbs/day)*
Total Phosphorus Atmospheric Load	33.1	0.178
Total Phosphorus Wasteload Allocation	116	0.318
Total Phosphorus Nonpoint Source Load Allocation	3,596	19.71
Total Phosphorus Margin of Safety	416.1	2.24
Total Phosphorus TMDL	4,161.2	22.446
Total Nitrogen Atmospheric Load	2,344.6	16.17
Total Nitrogen Wasteload Allocation	464	1.27
Total Nitrogen Nonpoint Source Load Allocation	31,419.5	218.6
Total Nitrogen Margin of Safety	3,803.1	26.23
Total Nitrogen TMDL	38,031.2	262.3

\*See Appendix B for Daily Load Calculations

**Table 11.** Cedar Creek Total Suspended Solids TMDL

Description	Allocations (tons/year)	Allocations (tons/day)*
Total Suspended Solids Wasteload Allocation	2.32	0.006
Total Suspended Solids Nonpoint Source Load Allocation	5,585.3	33.95
Total Suspended Solids Margin of Safety	620.85	3.773
Total Suspended Solids TMDL	6,208.5	37.73

\*See Appendix B for Daily Load Calculations

**Defined Margin of Safety:** The margin of safety provides some hedge against the uncertainty of variable annual total phosphorus and total nitrogen loads and the chlorophyll *a* endpoint and the variable annual sediment load and the Secchi depth endpoint. Therefore, the margin of safety is explicitly set at 10% of the total allocations for total phosphorus, total nitrogen and total suspended solids, which compensates for the lack of knowledge about the relationship between the allocated loadings and the resulting water quality. The margin of safety for TP and TN is 2.24 lbs/day and 26.23 lbs/day, respectively, while the margin of safety for TSS is 3.773 tons/day, as indicated in Tables 10 and 11.

**State Water Plan Implementation Priority:** Because Cedar Creek Lake has a regional benefit for recreation and because there is an intake on Cedar Creek located about three miles downstream from the lake dam that the City of Garnett uses for drinking water supply, this TMDL will be a **High** Priority for implementation.

**Unified Watershed Assessment Priority Ranking:** This watershed lies within the Upper Marais des Cygnes Basin (HUC 8: 10290101) with a priority ranking of 5 (High Priority for restoration work).

**Priority HUC 12:** The lower portion of the watershed is made up of the entire HUC 12 102901010506 while the lake, and its surrounding area, lies within a portion (~ 30%) of HUC 12 102901010507. The KBS bathymetric survey indicates heavy siltation occurring on the south end of the lake where Cedar Creek enters the lake indicating loading occurring along Cedar Creek hence, the priority HUC 12 will be 10290101506 focused on the riparian areas along Cedar Creek.

## **5. Implementation**

**Desired Implementation Activities:** There is a very good potential that agricultural best management practices will improve the condition of Cedar Creek Lake. Some of the recommended agricultural practices are as follows:

1. Implement soil sampling to recommend appropriate fertilizer applications on cultivated cropland.
2. Maintain conservation tillage and contour farming to minimize cropland erosion.
3. Promote and adopt continuous no-till cultivation to increase the amount of water infiltration and minimize cropland soil erosion and nutrient transports.
4. Install grass buffer strips along streams and drainage channels in the watershed.
5. Reduce activities within riparian areas.
6. Implement nutrient management plans to manage manure land applications and runoff potential.
7. Adequately manage fertilizer utilization in the watershed and implement runoff control measures.

### **Implementation Program Guidance:**

#### **Watershed Management Program – KDHE**

- a. Support selected Section 319 project activities including demonstration projects and outreach efforts dealing with erosion, sediment control and nutrient management.
- b. Provide technical assistance on practices geared to the establishment of vegetative buffer strips.
- c. Provide technical assistance on nutrient management in the vicinity of streams.
- d. Incorporate the provisions of this TMDL into WRAPS documents relating to Cedar Creek Lake.

#### **Water Resource Cost Share and Nonpoint Source Pollution Control Programs – KDA Division of Conservation**

- a. Apply conservation farming practices and/or erosion control structures, including no-till, terraces and contours, sediment control basins, and constructed wetlands.

- b. Provide sediment control practices to minimize erosion and sediment and nutrient transport.
- c. Re-evaluate nonpoint source pollution control methods.

**Riparian Protection Program – KDA Division of Conservation**

- a. Establish, protect or re-establish natural riparian systems, including vegetative filter strips and stream bank vegetation.
- b. Develop riparian restoration projects.
- c. Promote wetland construction to assimilate nutrient loadings.

**Buffer Initiative Program – KDA Division of Conservation**

- a. Install grass buffer strips near streams.
- b. Leverage Conservation Reserve Enhancement Program to hold riparian land out of production.

**Extension Outreach and Technical Assistance – Kansas State University**

- a. Educate agricultural producers on sediment, nutrient and pasture management.
- b. Educate livestock producers on livestock waste management and manure applications and nutrient management planning.
- c. Provide technical assistance on livestock waste management systems and nutrient management planning.
- d. Provide technical assistance on buffer strip design and minimizing cropland runoff.
- e. Encourage annual soil testing to determine capacity of fields to hold nutrients.

**NPDES – KDHE**

- a. Ensure any future NPDES permits in the watershed do not discharge excessive nutrients or TSS to streams above Cedar Creek Lake.

**Time Frame for Implementation:** Initial implementation will proceed over the years from 2013-2021. Additional implementation may be required over 2022-2030 to achieve the endpoints of this TMDL.

**Targeted Participants:** Primary participants for implementation will be agricultural producers within the Cedar Creek Lake watershed. A detailed assessment of sources conducted over 2013-2014 should include local assessments by conservation district personnel and county public works to survey, locate, and assess the following within the lake drainage area:

- 1. Total row crop acreage and fertilizer application rates,
- 2. Cultivation alongside lake,
- 3. Livestock use of riparian areas,
- 4. Fields with manure applications.

**Milestone for 2017:** In accordance with the TMDL development schedule for the State of Kansas, the year 2017 marks the next cycle of 303(d) activities in the Marais des Cygnes River Basin. At that point in time, data from 2015 at site LM040701 at Cedar Creek Lake will be reexamined to assess improved conditions in the lake.

**Delivery Agents:** The primary delivery agents for program participation will be the Kansas Department of Health and Environment, the Kansas Department of Agriculture Division of Conservation, the Natural Resources Conservation Service, the Kansas State University Extension Service and the Anderson County Conservation District. Producer outreach and awareness will be delivered by Kansas State Extension.

**Reasonable Assurances:**

Authorities: The following authorities may be used to direct activities in the watershed to reduce pollutants and to assure allocations of pollutant to point and nonpoint sources can be attained.

1. K.S.A. 65-171d empowers the Secretary of KDHE to prevent water pollution and to protect the beneficial uses of the waters of the state through required treatment of sewage and established water quality standards and to require permits by persons having a potential to discharge pollutants into the waters of the state.
2. K.S.A. 2-1915 empowers the Kansas Department of Agriculture – Division of Conservation to develop programs to assist the protection, conservation and management of soil and water resources in the state, including riparian areas.
3. K.A.R. 28-16-69 to 71 implements water quality protection by KDHE through the establishment and administration of critical water quality management areas on a watershed basis.
4. K.S.A 75-5657 empowers the Kansas Department of Agriculture – Division of Conservation to provide financial assistance for local project work plans developed to control nonpoint source pollution.
5. K.S.A. 82a-901, et. seq. empowers the Kansas Water Office to develop a state water plan directing the protection and maintenance of surface water quality for the waters of the state.
6. K.S.A. 82a-951 creates the State Water Plan Fund to finance the implementation of the Kansas Water Plan, including selected Watershed Restoration and Protection Strategies.
7. The Kansas Water Plan and the Marais Des Cygnes Basin Plan provide the guidance to state agencies to coordinate programs intent on protecting water quality and to target those programs to geographic areas of the state for high priority in implementation.
8. K.S.A. 32-807 authorizes the Kansas Department of Wildlife and Parks to manage lake resources.

**Funding:** The State Water Plan Fund annually generates \$16-18 million and is the primary funding mechanism for implementing water quality protection and pollutant reduction activities in the state through the *Kansas Water Plan*. The state water planning process, overseen by the

Kansas Water Office, coordinates and directs programs and funding toward watersheds and water resources of highest priority. Typically, the state allocates at least 50% of the fund to programs supporting water quality protection. Additionally, \$2 million has been allocated between the State Water Plan Fund and EPA 319 funds to support implementation of Watershed Restoration and Protection Strategies. This watershed and its TMDL are a High priority consideration for funding.

**Effectiveness:** Nutrient control has been proven effective through conservation tillage, contour farming and use of grass waterways and buffer strips. In addition, the proper implementation of comprehensive livestock waste management plans has proven effective at reducing nutrient runoff associated with livestock facilities. The key to success will be widespread utilization of conservation farming and proper livestock waste management within the watershed cited in this TMDL.

## **8. MONITORING**

KDHE will continue its 3-year sampling schedule in order to assess the trophic state of Cedar Creek Lake. Based on the sampling results, the 303(d) listing will be evaluated in 2022. Should impairment status continue, the desired endpoints under this TMDL may be refined and sampling conducted over the period 2022-2026 to assess progress in this implementation.

## **9. FEEDBACK**

**Public Notice:** Draft TMDLs for the Marais des Cygnes River Basin were made available through the active Internet Website at [www.kdhe.gov/tmdl](http://www.kdhe.gov/tmdl) on May 1, 2013.

**Public Hearing:** A Public Hearing was held May 23, 2013 in Ottawa to receive comment on this TMDL. Public comments for this TMDL were held open from May 4 through June 7, 2013. No comments were received for this TMDL.

**Basin Advisory Committee:** The Marais des Cygnes River Basin Advisory Committee met to discuss these TMDLs on September 14, 2012 in Fort Scott.

**Milestone Evaluation:** In accordance with the TMDL development schedule for the State of Kansas, the year 2017 marks a future cycle of 303(d) activities in the Marais des Cygnes Basin. At that point in time, sample data from Cedar Creek Lake will be reexamined to assess improved conditions in the lake. Should the impairment remain, adjustments to source assessment, allocation and implementation activities may occur.

**Consideration for 303d Delisting:** Cedar Creek Lake will be evaluated for delisting under Section 303(d), based on the monitoring data over 2012-2021. Therefore, the decision for delisting will come about in the preparation of the 2022 303(d) list. Should modifications be made to the applicable water quality criteria during the implementation period, consideration for delisting, desired endpoints of this TMDL and implementation activities may be adjusted accordingly.

**Incorporation into Continuing Planning Process, Water Quality, Management Plan and the Kansas Water Planning Process:** Under the current version of the Continuing Planning Process, the next anticipated revision would come in 2014, which will emphasize implementation of WRAPS activities. At that time, incorporation of this TMDL will be made into the WRAPS. Recommendations of this TMDL will be considered in the Kansas Water Plan implementation decisions under the State Water Planning Process for Fiscal Years 2012-2020.

*Developed 9/10/13*

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# Appendix A. BATHTUB Model Summary

## Model Inputs

### Case Data, Cedar Creek Lake

Global Variables			Model Options		
	Mean	CV		Code	Description
Averaging Period (yrs)	1	0.0	Conservative Substance	0	NOT COMPUTED
Precipitation (m)	0.938	0.2	Phosphorus Balance	2	2ND ORDER, DECAV
Evaporation (m)	1.237	0.3	Nitrogen Balance	2	2ND ORDER, DECAV
Storage Increase (m)	0	0.0	Chlorophyll-a	1	P, N, LIGHT, T
Atmospheric Loads (kg km <sup>-2</sup> yr <sup>-1</sup> )			Secchi Depth	1	VS. CHLA & TURBIDITY
Conserv. Substance	Mean 0	CV 0.00	Dispersion	1	FISCHER-NUMERIC
Total P	10	0.10	Phosphorus Calibration	1	DECAY RATES
Total N	709	0.05	Nitrogen Calibration	1	DECAY RATES
Ortho P	10	0.10	Error Analysis	1	MODEL & DATA
Inorganic N	709	0.05	Availability Factors	0	IGNORE
			Mass-Balance Tables	1	USE ESTIMATED CONCS
			Output Destination	2	EXCEL WORKSHEET

Segment Morphometry			Internal Loads (mg m <sup>-2</sup> day <sup>-1</sup> )		
Seg	Name	Group	Area km <sup>2</sup>	Depth m	Length Mixed Depth (m)
1	Cedar Creek Lake	1	1.5	2.9	4.75
				Mean	2.9
				CV	0.12
				Mean	0
				CV	0
				Mean	0.92
				CV	0.8
				Mean	0
				CV	0
				Mean	0
				CV	0
				Mean	0
				CV	0

Segment Observed Water Quality			MOD (ppb/day)		
Seg	Conserv	Total P (ppb)	Organic N (ppb)	TP - Ortho P (ppb)	HOD (ppb/day)
1	Mean 0	CV 104	Mean 1345	CV 0.5	Mean 35.2
					CV 1.9
					Mean 0.61
					CV 0.6
					Mean 8.67
					CV 0.7
					Mean 78
					CV 0.3
					Mean 0
					CV 0
					Mean 0
					CV 0

Segment Calibration Factors			MOD (ppb/day)		
Seg	Dispersion Rate	Total P (ppb)	Organic N (ppb)	TP - Ortho P (ppb)	HOD (ppb/day)
1	Mean 0	CV 1	Mean 1	CV 1	Mean 1
					CV 1
					Mean 1
					CV 1
					Mean 1
					CV 1
					Mean 1
					CV 1
					Mean 1
					CV 1

Tributary Data			Dr Area Flow (mm <sup>3</sup> /yr)		
Trib	Trib Name	Segment	Type	Area km <sup>2</sup>	Flow mm <sup>3</sup> /yr
1	Cedar Cr	1	1	157.8	30.2
					CV 0.1
					Mean 0
					CV 0
					Mean 3.10
					CV 0.5
					Mean 1786
					CV 0.5
					Mean 77.5
					CV 0.5
					Mean 750
					CV 0.5

Model Coefficients			MOD (ppb/day)		
	Mean	CV		Mean	CV
Dispersion Rate	1.000	0.70			
Total Phosphorus	0.996	0.45			
Total Nitrogen	0.611	0.55			
Chl-a Model	1.358	0.26			
Secchi Model	1.100	0.10			
Organic N Model	0.880	0.12			
TP-OP Model	1.000	0.15			
HODV Model	1.000	0.15			
MODV Model	1.000	0.22			
Secchi/Chla Slope (m <sup>2</sup> /mg)	0.025	0.00			
Minimum Os (m/yr)	0.100	0.00			
Chla Flushing Term	1.000	0.00			
Chla Temporal CV	0.620	0			
Avail. Factor - Total P	0.330	0			
Avail. Factor - Ortho P	1.930	0			
Avail. Factor - Total N	0.590	0			
Avail. Factor - Inorganic N	0.790	0			

Model Output – Current Condition  
Diagnostics, Cedar Creek Lake

Segment:	1	Cedar Creek Lake					
	Predicted Values--->			Observed Values--->			
<u>Variable</u>	<u>Mean</u>	<u>CV</u>	<u>Rank</u>	<u>Mean</u>	<u>CV</u>	<u>Rank</u>	
TOTAL P MG/M3	104.0	0.45	80.5%	104.0	0.30	80.5%	
TOTAL N MG/M3	1345.0	0.41	67.7%	1345.0	0.50	67.7%	
C.NUTRIENT MG/M3	71.9	0.32	80.9%	71.9	0.40	80.9%	
CHL-A MG/M3	35.2	0.43	95.7%	35.2	1.90	95.7%	
SECCHI M	0.6	0.35	22.7%	0.6	0.60	22.6%	
ORGANIC N MG/M3	905.4	0.33	89.8%	867.0	0.70	88.2%	
TP-ORTHO-P MG/M3	80.4	0.32	85.0%	78.0	0.30	84.3%	
ANTILOG PC-1	1265.4	0.53	89.5%	1247.0	1.13	89.3%	
ANTILOG PC-2	10.5	0.41	82.2%	10.4	1.37	81.8%	
(N - 150) / P	11.5	0.64	28.3%	11.5	0.63	28.3%	
INORGANIC N / P	18.6	2.43	31.9%	18.4	2.39	31.5%	
TURBIDITY 1/M	0.9	0.80	68.0%	0.9	0.80	68.0%	
ZMIX * TURBIDITY	2.7	0.81	41.5%	2.7	0.81	41.5%	
ZMIX / SECCHI	4.7	0.36	49.6%	4.8	0.59	49.8%	
CHL-A * SECCHI	21.5	0.57	85.4%	21.5	1.99	85.3%	
CHL-A / TOTAL P	0.3	0.50	80.5%	0.3	1.92	80.5%	
FREQ(CHL-a>10) %	95.7	0.07	95.7%	95.7	0.28	95.7%	
FREQ(CHL-a>20) %	72.6	0.32	95.7%	72.6	1.36	95.7%	
FREQ(CHL-a>30) %	47.9	0.58	95.7%	47.9	2.51	95.7%	
FREQ(CHL-a>40) %	30.3	0.81	95.7%	30.3	3.52	95.7%	
FREQ(CHL-a>50) %	19.0	1.00	95.7%	19.0	4.40	95.7%	
FREQ(CHL-a>60) %	12.1	1.17	95.7%	12.1	5.16	95.7%	
CARLSON TSI-P	71.1	0.09	80.5%	71.1	0.06	80.5%	
CARLSON TSI-CHLA	65.5	0.06	95.7%	65.5	0.28	95.7%	
CARLSON TSI-SEC	67.1	0.08	77.3%	67.1	0.13	77.4%	

Model Output – Current Condition  
Overall Water and Nutrient Balances, Cedar Creek Lake

Overall Water & Nutrient Balances

Overall Water Balance

Overall Water Balance				Averaging Period = 1.00 years				
<u>Trb</u>	<u>Type</u>	<u>Seq</u>	<u>Name</u>	<u>Area</u> <u>km<sup>2</sup></u>	<u>Flow</u> <u>hm<sup>3</sup>/yr</u>	<u>Variance</u> <u>(hm3/yr)<sup>2</sup></u>	<u>CV</u> <u>-</u>	<u>Runoff</u> <u>m/yr</u>
1	1	1	Cedar Cr	167.8	30.2	9.12E+00	0.10	0.18
PRECIPITATION				1.5	1.4	7.92E-02	0.20	0.94
TRIBUTARY INFLOW				167.8	30.2	9.12E+00	0.10	0.18
***TOTAL INFLOW				169.3	31.6	9.20E+00	0.10	0.19
ADVECTIVE OUTFLOW				169.3	29.8	9.51E+00	0.10	0.18
***TOTAL OUTFLOW				169.3	29.8	9.51E+00	0.10	0.18
***EVAPORATION					1.9	3.10E-01	0.30	

Overall Mass Balance Based Upon Component:

Overall Mass Balance Based Upon Component:				Predicted TOTAL P	Outflow & Reservoir Concentrations					
<u>Trb</u>	<u>Type</u>	<u>Seq</u>	<u>Name</u>	Load <u>kg/yr</u>	Load Variance			Conc	Export	
					<u>%Total</u>	<u>(kg/yr)<sup>2</sup></u>	<u>%Total</u>	<u>CV</u>	<u>mg/m<sup>3</sup></u>	<u>kg/km<sup>2</sup>/yr</u>
1	1	1	Cedar Cr	9362.0	99.8%	2.28E+07	100.0%	0.51	310.0	55.8
PRECIPITATION				15.0	0.2%	2.25E+00	0.0%	0.10	10.7	10.0
TRIBUTARY INFLOW				9362.0	99.8%	2.28E+07	100.0%	0.51	310.0	55.8
***TOTAL INFLOW				9377.0	100.0%	2.28E+07	100.0%	0.51	296.7	55.4
ADVECTIVE OUTFLOW				3094.2	33.0%	2.04E+06		0.46	104.0	18.3
***TOTAL OUTFLOW				3094.2	33.0%	2.04E+06		0.46	104.0	18.3
***RETENTION				6282.8	67.0%	1.55E+07		0.63		
Overflow Rate (m/yr)				19.8		Nutrient Resid. Time (yrs)			0.0482	
Hydraulic Resid. Time (yrs)				0.1462		Turnover Ratio			20.7	
Reservoir Conc (mg/m3)				104		Retention Coef.			0.670	

Overall Mass Balance Based Upon Component:

Overall Mass Balance Based Upon Component:				Predicted	Outflow & Reservoir Concentrations					
				TOTAL N						
				Load	Load Variance				Conc	Export
<u>Trb</u>	<u>Type</u>	<u>Seg</u>	<u>Name</u>	<u>kg/yr</u>	<u>%Total</u>	<u>(kg/yr)<sup>2</sup></u>	<u>%Total</u>	<u>CV</u>	<u>mg/m<sup>3</sup></u>	<u>kg/km<sup>2</sup>/yr</u>
1	1	1	Cedar Cr	53937.2	98.1%	7.56E+08	100.0%	0.51	1786.0	321.4
PRECIPITATION				1063.5	1.9%	2.83E+03	0.0%	0.05	755.9	709.0
TRIBUTARY INFLOW				53937.2	98.1%	7.56E+08	100.0%	0.51	1786.0	321.4
***TOTAL INFLOW				55000.7	100.0%	7.56E+08	100.0%	0.50	1740.1	324.9
ADVECTIVE OUTFLOW				40015.8	72.8%	2.89E+08		0.43	1345.0	236.4
***TOTAL OUTFLOW				40015.8	72.8%	2.89E+08		0.43	1345.0	236.4
***RETENTION				14984.9	27.2%	1.70E+08		0.87		
Overflow Rate (m/yr)				19.8		Nutrient Resid. Time (yrs)			0.1064	
Hydraulic Resid. Time (yrs)				0.1462		Turnover Ratio			9.4	
Reservoir Conc (mg/m3)				1345		Retention Coef.			0.272	

Model Output – 80% TP and 69% TN Reductions at Inflow  
Case Data, Cedar Creek Lake

Global Variables			Model Outputs			Code			Description		
	Mean	CV									
Averaging Period (yr)	1	0.0							0	NOT COMPUTED	
Precipitation (in)	0.938	0.2							2	2ND ORDER, DECAY	
Evaporation (in)	1.237	0.3							2	2ND ORDER, DECAY	
Storage Increase (in)	0	0.0							1	P, N, LIGHT, T	
Atmos. Loads (kg/dm <sup>2</sup> -yr)	Mean	CV							1	VS. CHLA & TURBIDITY	
Conserv. Substance	0	0.00							1	FISCHER-NUMERIC	
Total P	10	0.10							1	DECAY RATES	
Total N	709	0.05							1	DECAY RATES	
Ortho P	10	0.10							1	MODEL & DATA	
Inorganic N	709	0.05							0	IGNORE	
									1	USE ESTIMATED CONCS	
									2	EXCEL WORKSHEET	
Segment Morphometry											
Seg	Name	Outflow	Area	Depth	Length	Mixed Depth	Hypoc Depth	Non-Algal Turb	Internal Loads	Total P	Total N
		Segment	km <sup>2</sup>	m	km	m	m	(m <sup>-3</sup> )	Conc.	CV	CV
1	Cedar Creek Lake	0	1.5	2.9	4.75	2.9	0.12	0	0	0	0
Segment Observed Water Quality											
Seg	Conserve	Total P (ppb)	Total N (ppb)	Chl-a (ppb)	Secchi (m)	Organic N (ppb)	TP - Ortho P (ppb)	HOD (ppb/day)	MOD (ppb/day)	CV	CV
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	0	104	0.3	1345	0.5	35.2	1.9	0.61	0.6	867	0.7
Segment Calibration Factors											
Seg	Dispersion Rate	Total P (ppb)	Total N (ppb)	Chl-a (ppb)	Secchi (m)	Organic N (ppb)	TP - Ortho P (ppb)	HOD (ppb/day)	MOD (ppb/day)	CV	CV
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	1	0	1	0	1	0	1	0	1	0	1
Tributary Data											
Trib	Trib Name	Segment	Type	Dr Area	Flow (mm <sup>3</sup> /yr)	Conserve	Total P (ppb)	Total N (ppb)	Ortho P (ppb)	Inorganic N (ppb)	MOD (ppb/day)
				km <sup>2</sup>	Mean	CV	Mean	CV	Mean	CV	Mean
1	Cedar Cr	1	1	107.8	30.2	0.1	0	0.5	5.36	0.5	8.3
Model Coefficients											
	Mean	CV									
Dispersion Rate	1.000	0.70									
Total Phosphorus	0.936	0.45									
Total Nitrogen	0.611	0.55									
Chl-a Model	1.358	0.26									
Secchi Model	1.100	0.10									
Organic N Model	0.880	0.12									
TP-OP Model	1.000	0.15									
HOD Model	1.000	0.15									
MOD Model	1.000	0.22									
Secchi/Chla Slope (m <sup>2</sup> /mg)	0.075	0.00									
Minimum Chl (mg/L)	0.100	0.00									
Chl-a Flushing Term	1.000	0.00									
Chl-a Temporal CV	0.620	0									
Avail. Factor - Total P	0.330	0									
Avail. Factor - Ortho P	1.930	0									
Avail. Factor - Total N	0.530	0									
Avail. Factor - Inorganic N	0.730	0									

Model Output – 80% TP and 69% TN Reductions at Inflow  
Diagnostics, Cedar Creek Lake

**Predicted & Observed Values Ranked Against CE Model Development Dataset**

**Segment:**

**1 Cedar Creek Lake  
Predicted Values---**

**>**

**Observed Values--->**

<u>Variable</u>	<u>Mean</u>	<u>CV</u>	<u>Rank</u>	<u>Mean</u>	<u>CV</u>	<u>Rank</u>
TOTAL P MG/M3	30.2	0.43	30.4%	104.0	0.30	80.5%
TOTAL N MG/M3	477.4	0.41	12.3%	1345.0	0.50	67.7%
C.NUTRIENT MG/M3	20.2	0.38	23.9%	71.9	0.40	80.9%
CHL-A MG/M3	10.3	0.56	54.9%	35.2	1.90	95.7%
SECCHI M	0.9	0.58	42.4%	0.6	0.60	22.6%
ORGANIC N MG/M3	406.4	0.29	38.1%	867.0	0.70	88.2%
TP-ORTHO-P MG/M3	36.1	0.47	57.7%	78.0	0.30	84.3%
ANTILOG PC-1	188.0	0.64	42.0%	1247.0	1.13	89.3%
ANTILOG PC-2	6.8	0.61	54.4%	10.4	1.37	81.8%
(N - 150) / P	10.8	0.73	25.5%	11.5	0.63	28.3%
INORGANIC N / P	71.0	2.07	81.0%	18.4	2.39	31.5%
TURBIDITY 1/M	0.9	0.80	68.0%	0.9	0.80	68.0%
ZMIX * TURBIDITY	2.7	0.81	41.5%	2.7	0.81	41.5%
ZMIX / SECCHI	3.1	0.60	23.1%	4.8	0.59	49.8%
CHL-A * SECCHI	9.6	0.90	46.8%	21.5	1.99	85.3%
CHL-A / TOTAL P	0.3	0.56	80.9%	0.3	1.92	80.5%
FREQ(CHL-a>10) %	39.8	0.88	54.9%	95.7	0.28	95.7%
FREQ(CHL-a>20) %	8.4	1.68	54.9%	72.6	1.36	95.7%
FREQ(CHL-a>30) %	2.1	2.21	54.9%	47.9	2.51	95.7%
FREQ(CHL-a>40) %	0.6	2.61	54.9%	30.3	3.52	95.7%
FREQ(CHL-a>50) %	0.2	2.93	54.9%	19.0	4.40	95.7%
FREQ(CHL-a>60) %	0.1	3.20	54.9%	12.1	5.16	95.7%
CARLSON TSI-P	53.3	0.12	30.4%	71.1	0.06	80.5%
CARLSON TSI-CHLA	53.5	0.10	54.9%	65.5	0.28	95.7%
CARLSON TSI-SEC	61.0	0.14	57.6%	67.1	0.13	77.4%

Model Output – 80% TP and 69% TN Reductions at Inflow  
Overall Balances, Cedar Creek Lake

Overall Water Balance				Averaging Period = 1.00 years				
<u>Trb</u>	<u>Type</u>	<u>Seg</u>	<u>Name</u>	<u>Area</u> <u>km<sup>2</sup></u>	<u>Flow</u> <u>hm<sup>3</sup>/yr</u>	<u>Variance</u> <u>(hm3/yr)<sup>2</sup></u>	<u>CV</u> <u>-</u>	<u>Runoff</u> <u>m/yr</u>
1	1	1	Cedar Cr	167.8	30.2	9.12E+00	0.10	0.18
PRECIPITATION				1.5	1.4	7.92E-02	0.20	0.94
TRIBUTARY INFLOW				167.8	30.2	9.12E+00	0.10	0.18
***TOTAL INFLOW				169.3	31.6	9.20E+00	0.10	0.19
ADVECTIVE OUTFLOW				169.3	29.8	9.51E+00	0.10	0.18
***TOTAL OUTFLOW				169.3	29.8	9.51E+00	0.10	0.18
***EVAPORATION					1.9	3.10E-01	0.30	

Overall Mass Balance Based Upon Component:				Predicted TOTAL P	Outflow & Reservoir Concentrations			
<u>Trb</u>	<u>Type</u>	<u>Seg</u>	<u>Name</u>	<u>Load</u> <u>kg/yr</u>	<u>Load Variance</u> <u>(kg/yr)<sup>2</sup></u>	<u>Conc</u> <u>mg/m<sup>3</sup></u>	<u>Export</u> <u>kg/km<sup>2</sup>/yr</u>	
1	1	1	Cedar Cr	1872.4	99.2%	9.12E+05	100.0%	0.51
			PRECIPITATION	15.0	0.8%	2.25E+00	0.0%	0.10
			TRIBUTARY INFLOW	1872.4	99.2%	9.12E+05	100.0%	0.51
			***TOTAL INFLOW	1887.4	100.0%	9.12E+05	100.0%	0.51
			ADVECTIVE OUTFLOW	898.4	47.6%	1.61E+05		0.45
			***TOTAL OUTFLOW	898.4	47.6%	1.61E+05		0.45
			***RETENTION	989.0	52.4%	4.88E+05		0.71
			Overflow Rate (m/yr)	19.8		Nutrient Resid. Time (yrs)		0.0696
			Hydraulic Resid. Time (yrs)	0.1462		Turnover Ratio		14.4
			Reservoir Conc (mg/m3)	30		Retention Coef.		0.524

Overall Mass Balance Based Upon Component:				Predicted TOTAL N	Outflow & Reservoir Concentrations			
<u>Trb</u>	<u>Type</u>	<u>Seg</u>	<u>Name</u>	<u>Load</u> <u>kg/yr</u>	<u>Load Variance</u> <u>(kg/yr)<sup>2</sup></u>	<u>Conc</u> <u>mg/m<sup>3</sup></u>	<u>Export</u> <u>kg/km<sup>2</sup>/yr</u>	
1	1	1	Cedar Cr	16187.2	93.8%	6.81E+07	100.0%	0.51
			PRECIPITATION	1063.5	6.2%	2.83E+03	0.0%	0.05
			TRIBUTARY INFLOW	16187.2	93.8%	6.81E+07	100.0%	0.51
			***TOTAL INFLOW	17250.7	100.0%	6.81E+07	100.0%	0.48
			ADVECTIVE OUTFLOW	14203.7	82.3%	3.61E+07		0.42
			***TOTAL OUTFLOW	14203.7	82.3%	3.61E+07		0.42
			***RETENTION	3047.0	17.7%	8.15E+06		0.94
			Overflow Rate (m/yr)	19.8		Nutrient Resid. Time (yrs)		0.1204
			Hydraulic Resid. Time (yrs)	0.1462		Turnover Ratio		8.3
			Reservoir Conc (mg/m3)	477		Retention Coef.		0.177

## Appendix B. Calculation of Daily Loads

### Conversion to Daily Loads as Regulated by EPA Region VII\*

The TMDL has estimated annual average loads for TN, TP and TSS that if achieved should meet the water quality targets. A recent court decision often referred to as the “Anacostia decision” has dictated that TMDLs include a “daily” load (Friend of the Earth, Inc v. EPA, et al.).

Expressing this TMDL in daily time steps could be misleading to imply a daily response to a daily load. It is important to recognize that the growing season mean chlorophyll *a* is affected by many factors such as: internal lake nutrient loading, water residence time, wind action and the interaction between light penetration, nutrients, sediment load and algal response.

To translate long-term averages to maximum daily load values, EPA Region 7 has suggested the approach describe in the Technical Support Document for Water Quality Based Toxics Control (EPA/505/2-90-001)(TSD).

$$\text{Maximum Daily Load (MDL)} = (\text{Long-Term Average Load}) * e^{[Z\sigma - 0.5\sigma^2]}$$

$$\text{where } \sigma^2 = \ln(CV^2 + 1)$$

CV = Coefficient of variation = Standard Deviation / Mean

Z = 2.326 for 99<sup>th</sup> percentile probability basis

LTA= Long Term Average

ATM = Atmospheric Load

LA= Load Allocation

WLA = Wasteload Allocation

MOS= Margin of Safety

Parameter	LTA	CV	$e^{[Z\sigma - 0.5\sigma^2]}$	MDL	Atm LA lbs/day	LA	WLA lbs/day	MOS (10%)
TP	4,161.2 lbs/year	0.32	1.97	22.446 lbs/day	0.178	19.71 lbs/day	0.318	2.24 lbs/day
TN	38,031.2 lbs/year	0.46	2.52	262.3 lbs/day	16.17	218.6 lbs/day	1.27	26.23 lbs/day
TSS	6,208.5 tons/year	0.39	2.22	37.73 tons/day	N/A	33.95 tons/day	12.7	3.773 tons/day

### Maximum Daily Load Calculation

Annual TP Load = 4,161.2 lbs/yr

$$\begin{aligned}\text{Maximum Daily TP Load} &= [(4,161.2 \text{ lbs/yr}) / (365 \text{ days/yr})] * e^{[2.326 * (0.312) - 0.5 * (0.312)^2]} \\ &= 22.446 \text{ lbs/day}\end{aligned}$$

Annual TN Load = 39,213 lbs/yr

$$\begin{aligned}\text{Maximum Daily TN Load} &= [(38,031.2 \text{ lbs/yr})/(365 \text{ days/yr})] * e^{[2.326*(0.438) - 0.5*(0.438)^2]} \\ &= 262.3 \text{ lbs/day}\end{aligned}$$

Annual TSS Load = 6,208.5 tons/yr

$$\begin{aligned}\text{Maximum Daily TSS Load} &= [(6,280.5 \text{ tons/yr})/(365 \text{ days/yr})] * e^{[2.326*(0.372) - 0.5*(0.372)^2]} \\ &= 37.73 \text{ tons/day}\end{aligned}$$

### **Margin of Safety (MOS) for Daily Load**

Annual TP MOS = 416.1 lbs/yr

$$\begin{aligned}\text{Daily TP MOS} &= [(416.1 \text{ lbs/yr})/(365 \text{ days/yr})] * e^{[2.326*(0.312) - 0.5*(0.312)^2]} \\ &= 2.24 \text{ lbs/day}\end{aligned}$$

Annual TN MOS = 3,803.1 lbs/yr

$$\begin{aligned}\text{Daily TN MOS} &= [(3,803.1 \text{ lbs/yr})/(365 \text{ days/yr})] * e^{[2.326*(0.438) - 0.5*(0.438)^2]} \\ &= 26.23 \text{ lbs/day}\end{aligned}$$

Annual TSS MOS = 620.85

$$\begin{aligned}\text{Daily TSS MOS} &= [(620.85 \text{ tons/yr})/(365 \text{ days/yr})] * e^{[2.326*(0.372) - 0.5*(0.372)^2]} \\ &= 3.773 \text{ tons/day}\end{aligned}$$

\*Source- *Technical Support Document for Water Quality-based Toxics Control (EPA/505/2-90-001)*

### **Calculation of Daily Wasteload for Discharging Lagoons:**

Daily wasteload allocations were calculated as:

$$\begin{aligned}\text{Design Flow (cfs)} \times \text{Parameter Concentration (mg/L)} \times \text{Unit Conversion Factor (5.4)} \\ = \text{Wasteload in units of lbs/day}\end{aligned}$$

$$\begin{aligned}\text{Wasteload in units of pounds/day} \times 365 \\ = \text{Wasteload in units of lbs/year}\end{aligned}$$

For Welda SD No 1:

TP limit = 2 mg/L; TN limit = 8 mg/L; TSS limit = 80 mg/L; Design Flow = 0.0294

Daily Wasteload Allocation for TP = 2 x 0.0294 x 5.4 = 0.318 lbs/day x 365 = 116 lbs/year

Daily Wasteload Allocation for TN = 8 x 0.0294 x 5.4 = 1.27 lbs/day x 365 = 464 lbs/year

Daily Wasteload Allocation for TSS = 80 x 0.0294 x 5.4 = 12.7 lbs/day x 365 = 4,636 lbs/year

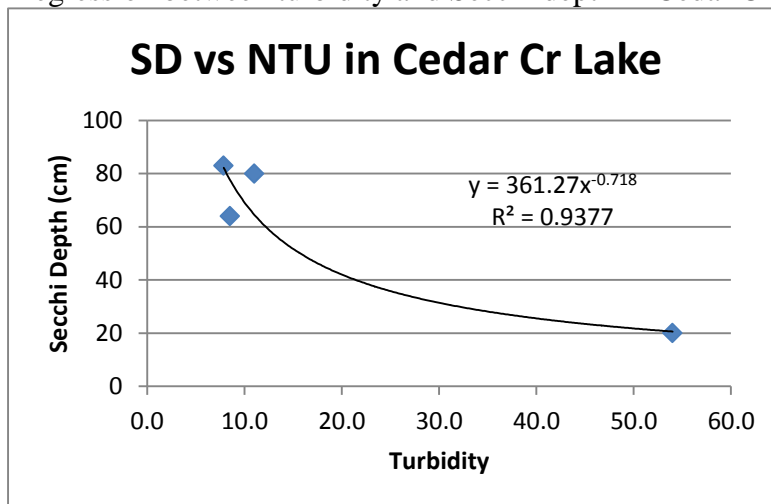
## Appendix C. Development of TSS/Secchi depth endpoint in Cedar Creek Lake.

Regression equations were developed for Secchi depth and turbidity (Figure C1) and TSS and turbidity (Figure C2) using Secchi depth, turbidity and TSS data for the period of record (Table C1).

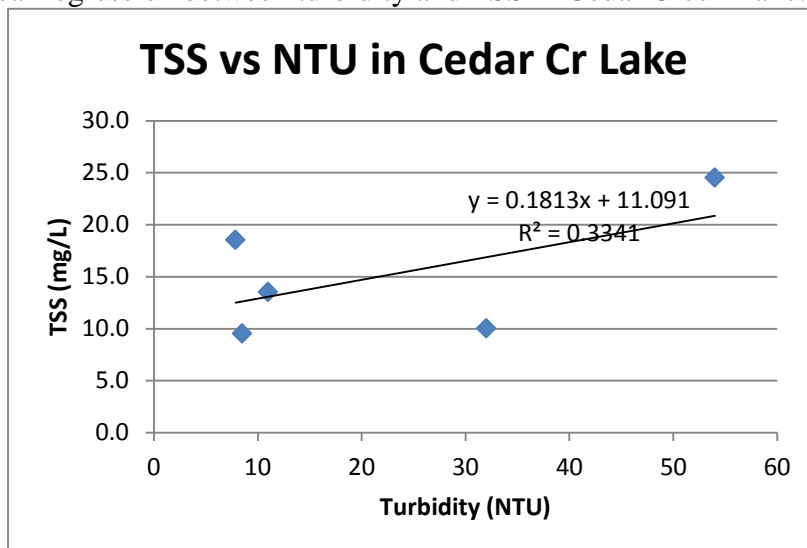
**Table C1.** Cedar Creek Lake water quality data.

Date	SD (cm)	NTU	TSS
7/13/1993	20	54.0	24.5
8/10/1998	64	8.5	9.5
6/11/2002	30	32.0	10.0
7/31/2006	80	11.0	13.5
8/10/2009	88	No data	14.0
7/9/2012	83	7.9	18.5

**Figure C1.** Power regression between turbidity and Secchi depth in Cedar Creek Lake.



**Figure C2.** Linear regression between turbidity and TSS in Cedar Creek Lake.



The TSS target of 12.3 mg/L was developed using a Secchi depth target of 0.9 m and the equations in Figures C1 and C2 as detailed in Table C2.

**Table C2.** TSS target development in Cedar Creek Lake.

Secchi/NTU Regression	Secchi Depth Target (cm)	Turbidity (NTU)
$y=361.22x^{-.718}$	90	6.9
NTU/TSS Regression	Turbidity (NTU)	TSS (mg/L)
$y=.1813x+11.091$	6.9	12.3